MINE RECLAMATION

A Handbook

Indian Council of Forestry Research & Education

(An autonomous body of Ministry of Environment, Forest & Climate Change, Government of India)

A HANDBOOK ON MINE RECLAMATION

A HANDBOOK

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
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Foreword

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ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need to present its research findings to the stakeholders in a simple and lucid manner, to improve the visibility and relevance of ICFRE. Therefore it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE be published in the form of operational manuals/user manuals. It is also desirable that the manual should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

The handbook on "Mine Reclamation" incorporates comprehensive information on various aspects of mine reclamation including extent and causes of land degradation, scope and reclamation scenario in India, approaches and strategies of reclamation of mine spoils, essentials of eco-friendly mining and species prescriptions for different mining scenarios. The handbook also contains outstanding reclamation efforts of various ICFRE institutes in recent past.

I hope that this handbook will help diverse stakeholders like public and private mining companies, state forest departments, research and educational institutions etc. in developing appropriate reclamation strategies and furthering advance research contributing to environmental amelioration.

Dr. Suresh Gairola

Preface

Dr. Sanjay Singh
NSMC, Mine Reclamation

Minerals constitute the back-bone for economic growth for any nation. India has been eminently and enormously endowed with this gift of nature. There are many evidences that exploitation of minerals like coal, iron-ore, copper, lead-zinc in the country from time immemorial. The first recorded history of mining in India dates back to 1774 when English Company was granted permission by the East India Company for mining coal in Raniganj. In 1880 M/s John Taylor and Sons Ltd. started gold mining in Kolar Gold Fields in Karnataka. In Digboi, Assam the first oil well was drilled in the year 1866 which was just seven years after the first ever oil well was drilled anywhere in the world viz in Pennsylvania State, USA in 1859.

Minerals and mining sector contributes significantly to the economic growth and development of India in the form of exports, raw material to other industries in the country and finally vast employment opportunities and a high rate of wages. The Indian mining industry currently employs over 1.1 million people. Mining also yields foreign exchange and accounts for a significant portion of gross domestic product. Thus, the economic opportunities and wealth generated by mining for the country are substantial.

However, mining is associated with severely adverse effects on the environment including loss of biodiversity, erosion, contamination of surface water, ground water, and soil. Mining causes physical destruction to the surrounding land by creating landscape blots such as open pits and piles of waste rock. Such disruptions result in the deterioration of the area's flora and fauna. In most of the cases the surface features and vegetation that were present before mining activities cannot be replaced after the process has ended. Hazardous activities start right from clear felling of vegetation for mining and allied activities which accentuate as the operations increase in intensity. Loss of soil productivity, biological diversity, health and environmental hazards due to air, water and noise pollution microclimatic changes etc. are the major problems of the mining process.

Reclamation on mined areas thus pose a great challenge for ecologists, biologists, agriculturists, engineers, soil scientist, and foresters as well who are invariably concerned about restoration of this disturbed ecosystem. Therfore, Indian Council of Forestry Research and Education has come up this operational manual incorporating comprehensive information on various aspects of mine reclamation including extent and causes of land degradation, scope and reclamation scenario in India, approaches and stretegies of reclamation of mine spoils, essentials of ecofriendly mining and species prescriptions for different mining scenarios. The manual also contains outstanding reclamation efforsts of various ICFRE institutions in recents past.

We earnestly feel that it will serve as refrence manual on mine reclamation and help public and private mining companies, state forest departments, reaseach and educational institutions as per their requirements for developing appropriate reclamation stretegies and furthering advance research contributing to environmental amelioration.

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TARGET GROUP

1. Public and private sector mining companies
2. State forest departments
3. Forestry research institutions
4. Universities/educational institutions
5. Researchers
6. Policy makers

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1 INTRODUCTION
LAND DEGRADATION: EXTENT AND CAUSES

India has a geographic area of 328.72 million hectare, of which land degradation is estimated to be 96.4 million hectare or 29.32% of land area–as much as Rajasthan, Madhya Pradesh and Maharashtra put together–according to the 2016 study by Space Applications Centre of the Indian Space Research Organisation (ISRO).

Land degradation is occurring due to the natural and human induced causes, like wind erosion, water logging and mining.

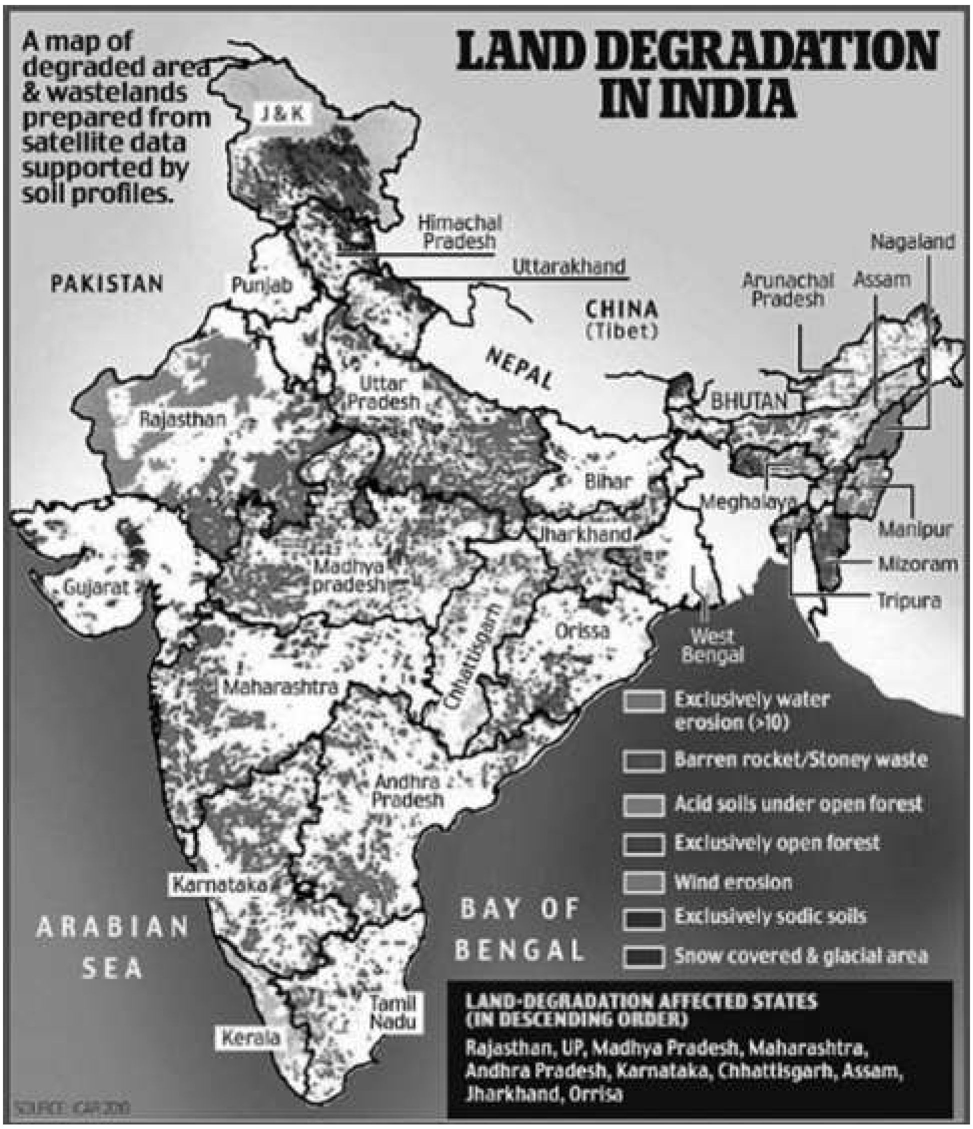

Fig 1. *Extent of land degradation in India*

PROBLEM SOILS

Nearly 50 % of the irrigated land in the arid and semi-arid regions has some degree of soil salinization problems. The phenomenon of accumulation of excess salt/acid in the root zone, results in a partial or complete loss of soil productivity and such soil is defined as *'Problem (alkali, saline and acid) Soils'* and exist mainly in arid and semi-arid regions.

Salt affected soils are also found extensively in sub-humid and humid climates, particularly in the coastal regions where the ingress of sea water through estuaries and rivers causes large-scale salinization.

The Food and Agriculture Organization (FAO) uses the term *solonetz* (from the Russian sol etz "strongly salty") to describe sodic soils. The salt in soils dissolves in the soil water and damages plant growth by preventing the plants from getting required water from the soil, due to increase in the energy required to remove a given quantity of water from a salt solution with increased salt concentration of the solution.

Soil salinity is also a serious problem in areas where groundwater with high salinity is used for irrigation. Most serious salinity problem is being faced where canal irrigation is major source of irrigation. The alkali soils are largely predominant in the Indo-Gangetic plains encompassing States of Punjab, Haryana, Uttar Pradesh and Bihar and partly in states like, Chhattisgarh, Rajasthan, Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh and Tamil Nadu.

The saline soils are found mainly in the states of Gujarat, Bihar, Haryana, Rajasthan, Maharashtra, Odisha, Andhra Pradesh, Kerala, Tamil Nadu, Uttar Pradesh and West Bengal whereas isolated patches of problem soils also occur in many other States.

The problem of acid soils exists in most of the states except Gujarat, Punjab, Rajasthan and Uttar Pradesh. With the advent of canal irrigation, area under problem soils is increasing day by day, due to which large fertile cultivated lands is losing production potential across the country.

The major driving factors for creation of alkalinity, salinity and acidity in the soils may be any one or mixed of means listed below:

- *In arid regions, where evaporation exceeds the precipitation, the soluble salts accumulates near the soil surface/root zone.*
- *Ground water of arid regions usually contains considerable quantities of soluble salts and when it is used for irrigation, damages the soil. The extent of damage not only depends upon salt content of irrigation water but also on nature of salts and type of soils on which water is applied. Testing of well/ tubewell water is not done by the farmers and they continue to irrigate lands till productivity is lost.*
- *At times, salts may have originated directly from chemical weathering of rocks and sodium salts are more harmful than calcium and magnesium salts.*
- *An excessive application of irrigation water and seepage from canals and tanks raises the ground water level which result in continuous accumulation of salt at surface through capillary action and evaporation. The rate of accumulation would be much faster if quality of subsurface water is saline.*
- *Poor drainage keeps salts in surface soil and prevents leaching of salts down below the root zone. Many saline soils in command areas are formed due to inadequate and impaired drainage.*

- *Soil salinization in coastal area is primarily due to the accumulation of salts from inundated sea water. Irrigation water contains high concentration of soluble salts, particularly sodium salts which may also lead to salinity.*

MINED OUT AREAS

Mine wasteland generally comprises the bare stripped area, loose soil piles, waste rock and overburden surfaces, subsided land areas, other degraded land by mining facilities, among which the waste rocks often pose extreme stressful conditions for restoration.

Fig 2. *Degradation through open cast mining*

The mining disrupts the aesthetics of the landscape along with it disrupts soil components such as soil horizons and structure, soil microbe populations, and nutrient cycles those are crucial for sustaining a healthy ecosystem and hence results in the destruction of existing vegetation and soil profile (Kundu and Ghose, 1997).

The overburden dumps include adverse factors such as elevated bioavailability of metals; elevated sand content; lack of moisture; increased compaction; and relatively low organic matter content. Acidic dumps may release salt or contain sulphidic material, which can generate acid-mine drainage (Ghose 2005). The effects of mine wastes can be multiple, such as soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Wong 2003; Sheoran *et al.* 2008).

2 LAND RECLAMATION

SCOPE

Land reclamation is the process of improving lands to make them suitable for a more intensive use in agriculture, forestry and/or environmental amelioration. Reclamation efforts deal with specific strategies and methods for varied degradation scenarios such as improvement of rainfall-deficient areas, salty or alkali lands, water logged lands, tidal marshes, revegetation of mine spoil areas etc.

Reclamation is the process by which derelict or highly degraded lands are returned to productivity, and by which some measures of biotic function and productivity is restored. Long term mine spoil reclamation requires the establishment of stable nutrient cycles from plant growth and microbial processes (Singh *et al.*, 2002; Lone *et al.*, 2008; Kavamura and Esposito, 2010).

RECLAMATION SCENARIO IN INDIA

Land reclamation in India has traditionally been associated with the reclamation of saline and sodic agricultural soils (Abrol 1986). However within the last few decades have there been numerous attempts to restore lands disturbed by mining to an acceptable or useful vegetative condition (Gupta 1979; Mann and Chatterji 1979; Prad and Chadhar, 1987).

At present most of the reclamation work in India is a descriptive, making assessment of current environmental problems generally excluding air, soil and water degradation assessment and drawing up short term future environmental management and reclamation plans. This state of affairs is partly due to the requirements of the current legislation, where environmental management and land reclamation plans are required from mining companies to obtain mining licences; particularly, in scenarios where diversion of forested land is involved. A licence will only be granted if the company can demonstrate that it has an equal amount of non-forested land elsewhere that be afforested almost immediately. This is known as compensatory afforestation. If only degraded forest land is available, then twice the number of trees has to be planted on that land.

Where mineral deposits are near the surface of the earth, frequently they are exposed for mining by excavating the entire overburden, called surface mining , widely used as a method for extracting coal, phosphate deposits, gypsum, gravel, limestone, copper, iron, and other minerals. The overburden removed to expose the mined deposit is dropped in a series of generally conical mounds.

The problem of revegetation is complicated by the irregular, frequently steep topography of the spoil-bank area and the raw, infertile nature of the spoil material. Smoothing of the area is likely to result in excessive compaction of the spoil material, rendering it less suited to plant growth. For this reason, reclamation of spoil banks is generally confined to reforestation, to development of grazing land, or to reclaiming for recreational areas. Reclamation to the point where cultivated crops can be produced is rare. In mine spoil, however, drainage is generally good, and the acid constituents will be removed by leaching in a period of years.

Land reclamation in India primarily involves the reestablishment of forest cover, whether on or off the mine site, by the planting of container grown tree stocks. Some of the most commonly used species include *Eucalyptus, Cassia, Acacia, Prosopis, Azadirachta, Lucaena* and *Dalbergia*. However, considering the wide range of climatic conditions prevailing in the country, it is evident that reclmantion efforts have not utilized native species in prudent manner.

In the arid areas, grasses, *Cynodon dactylon* and *Pennisetum typhoides*, have been successfully established on zinc-lead tailings along with several shrubby ornamentals including *Lantana* species (Chaphekar 1989). This use of grasses, however, appears to an exception to general revegetation practice.

RECLAMATION PLANNING

The goals for reclamation can be viewed from theoretical and practical perspectives. Simply put, a reclamation project should aim to produce environmentally sound and stable conditions that ultimately integrate the disturbed area into the general ecosystem. Accordingly, a reclamation plan should address the topographic reconstruction, topsoil replacement or substitution, revegetation and site monitoring and maintenance.

TOPOGRAPHIC RECONSTRUCTION

Most natural landscapes are composed of drainage basins which in turn consist of hill slopes and stream channels in an orderly arrangement for effectively conveying water and sediment which get disturbed during mining. The character of the post reclamation equilibrium differs from that of the pre-disturbance equilibrium because geologic and soil properties cannot be replicated.

Topographic design therefore should be based upon expected properties following reclamation rather than pre-disturbance properties. Care is also to be taken to minimize erosion and runoff where ground cover is temporarily removed. Special flood-control and sediment-control measures are necessary to prevent damage. The importance of topographic reconstruction cannot be neglected because the resulting landforms are the foundation upon which other reclamation practices are executed and eventual land uses take place.

REPLACEMENT OF TOPSOIL AND SOIL RECONSTRUCTION

Revegetations of the reclaimed surfaces require a suitable growth medium. In most cases, top soils have the necessary physical, chemical and biological properties to sustain plant development, although the use of substitute geologic materials is often inevitable.

In general top soil layers are higher in organic matter, microbial activity, and nutrients than underlying subsoil or geologic material. Top soils contain significant seed bank that can be used to great advantage in revegetation. Stock piling and reuse of top soil almost always facilitates achievement of reclamation goals. When spoil or other course-textured materials are revegetated without top soil covers, moisture stress induced by compaction, high course-fragment contents, salts, and high surface heat is usually the primary factor limiting growth. Therefore as far as practicable the top soil should be stored at a suitable place with proper precautionary measures so that it could be utilized during reclamation process. Some of the best practices involved in the topsoil management are:

- *Scrap the top soil prior to drilling and blasting.*
- *Scrapped topsoil should be used immediately for plantation work; otherwise it should be stacked in a designated area.*
- *Stacked topsoil should be surrounded by proper embankments to prevent erosion.*
- *Stacked topsoil should be stabilized further by grasses and bush to protect from the wind.*

Fig 3. *Excellent top soil managent at a CIL mine*

REVEGETATION

Revegetation is a principal goal of reclamation and results in many desirable secondary water quality and aesthetic benefits. Revegetation goals are from simple erosion control to the full restoration of complex native communities. The approaches and protocols employed, therefore, are specific for region, site and land use.

The development of a permanent vegetation cover should aim to establish a plant community that will maintain itself indefinitely without attention or artificial aid, and support native fauna. To extract better results, some ecological variables must be considered while selecting species for plantation. These are; their capacity to stabilize soil, soil organic matter and available soil nutrients, and under storey development.

Fig 4. *Recent plantation on the backfilled area*

In the initial stages of revegetation quick growing grasses with short life cycle, legumes and forage crops are recommended. It will improve the nutrient and organic matter content in soil. Plantation of mixed species of economic importance should be done after 2-3 years of growing grasses. While selecting suitable species for plantation in mine area, the following considerations have to be taken into account:

- *Planting pollutant tolerant species.*
- *Plants of fast growing with thick vegetation foliage.*
- *Indigenous/exotic plants species with easy adaptability to the locality.*
- *Socio economic requirement of the people of the surrounding area.*
- *The benefits of vegetation are of immense benefit to the local inhabitants.*

3 RECLAMATION SCENARIOS

Mine reclamation involvs a number of scenarios where diverse type of soil related problems need to be addressed. These may include salinity, alkalinity/sodicity, acidity, waterlogging, desertification, coastal area destabilization etc.

Major advancements in salinity research are due to US Salinity Research Laboratory, Riverside California; Institute of Soils, Hungary, and Central Soil Salinity Research Institute (CSSRI), Karnal, India (Szabolcs, 1977; Tyagi and Minhas, 1998; Wallender and Tanji, 2011). The researches at CSSRI and at several state agricultural universities in India have led to problem specific technology development in the last 50 years (Agarwal *et al.*, 1982; Abrol *et al.*, 1988; Tyagi and Minhas, 1998; CSSRI, 2004).

The solution of alkalinity/sodicity revolves mainly around application of chemical amendments along with use of appropriate crops and varieties and good agronomic practices. However, in revent past the emphasis for reclaiming salt-affected soils has been shifted on harnessing the synergy of built-in plant salt tolerance and the chemical amendments (Singh *et al.* 2004). Advantage of salt tolerant crop varieties to reduce the requirements of chemical amendments was successfully tested and out-scaled (Singh *et al.,* 2004; Tyagi and Singh, 2009).

ALKALI SOILS

In alkali soils, the Exchangeable Sodium Percentage (ESP) is greater than 15, pH is more than 8.2 and Electric Conductivity (EC) is below 4 ds/m.

Application of chemical amendments, which was mostly gypsum or in some cases pyrites, has generally been the approach reclamation of alkali lands but Indian researches have attempted various innovations leading to reduction in cost and improvement in efficiency of water use.

A major advancement in technology of alkali land reclamation was the field tested recommendation on the reduction in doses of chemical amendment - a major item in reclamation cost. But field experiments conclusively established that gypsum requirement could be reduced by 50 % of what was required for complete neutralization of exchangeable sodium, without any appreciable loss of crop productivity over a time span of 3-5 years (Abrol *et al.*, 1988).

General recommended interventions for reclamation of alkali soils have been listed below:

- *Field bunding, land shaping, construction of irrigation channels and field drains/link drains etc.*
- *Application of soil amendments (Gypsum/Pyrite) at the average rate of 5 tonnes per ha and it's mixing with soil when temperature is around 40 degree centigrade.*
- *Green manuring and its mulching in the soil for increasing organic carbon in the soil and high degree use of Farm Yard Manure (FYM).*
- *Application of soil test based chemical fertilizers and micro-nutrients to ensure judicious and balance use of fertilizers.*
- *Growing of suitable crops/horticultural/agroforestry species including food, fuel and fodder plantations depending upon soil and slope conditions for one year.*

- *Casualty replacement and post planting care in case of horticulture and agroforestry plantation for about three years.*

- *Organization of skill development and awareness programmes for adoption of recommended package of practices on continuous basis to prevent reoccurrence of such problem soils.*

Some of the potential species for reclamation of alkanile wastelands have been presented in the Table 1.

Table 1. Relative tolerance of tree species to soil alkalinity

Average soil pH in 1:2 soil water suspension	Fuelwood/timber tree species	Fruit tree species
>10.0	*Prosopis juliflora, Acacia nilotica, Casuarina equisetifolia*	*Acchras japota*
9.0-10.0	*Tamarix articulata, Terminalia arjuna, Albizzia lebbeck, Pongamia pinnata, Sesbania sesban, Eucalyptus tereticornis*	*Zizyphus mauritiana. Sapindus laurifolius, Emblica officinalis, Carissa carandas, Psidium guajava, Phoenix dactylifera, Aegle marmelos*
8.2-9.0	*Dalbergia sissoo, Morus alba, Grevillea robusta, Azadirachta indica, Tectona grandis, Populus deltoides*	*Punica granatum, Pyrus persica, Pyrus communis, Vitis vinifera, Mangifera indica, Syzygium cumini*

SALINE SOILS

Saline soils have excessive concentration of natural soluble salts, mainly chlorides, sulphates and carbonates of calcium, magnesium and sodium. In such soil Electrical Conductivity (EC) of saturated soil extract is more than 4 ds/m, Exchangeable Sodium Percentage (ESP) is less than 15 and pH is also less than 8.2. Such soils are called “saline soils” or “white alkali” or “solonchack” soils.

The reclamation of salt-affected soils follows the exact reverse of the process by which they are formed. The first step is to improve the drainage so that upward movement of ground water to the soil surface ceases and water applied to the surface can move down through the soil profile. Then fresh no saline water is applied to the surface by irrigation. This fresh water washes out the excess salts, which are carried away in the drainage water.

In the case of sodic soils, amendments that will supply a fresh source of soluble calcium to replace the sodium adsorbed by the soil are added and leaching is carried out until the replaced sodium is removed. Gypsum (calcium sulfate) is the most common amendment used to supply calcium for the reclamation of sodic soils.

General recommended interventions for reclamation of saline soil have been presented below:

- *Field bunding, land shaping, construction of irrigation channel, construction of peripheral bunds, sluice gate, farm ponds/water harvesting structure, etc.*

- *Construction of surface/sub-surface drainage as per need of the area for lowering the ground water level and also for flashing salt accumulated upper soil layer crop root zone.*

- *Green manuring and its mulching into soil for increasing organic carbon in the soil with thrust on use of F.Y.M.*
- *Application of soil test based chemical fertilizers and micro-nutrients to ensure judicious and balance use of such fertilizers.*
- *Growing of suitable crops/horticultural/agroforestry species including food, fuel and fodder plantations as per land capabilities depending upon soil and slope conditions for complete one year.*
- *Casualty replacement and post planting care, horticulture and agroforestry plantation for about three years.*
- *Organization skill development and awareness programme for adoption of recommended package of practices on continuous basis to prevent reoccurrence of problem soils.*

WATERLOGGED SALINE SOILS

In India the need for provision of drainage and development of appropriate technology for reclamation of waterlogged saline lands in irrigated areas, has been emphasized as early as 1928 (Royal Commission on Agriculture, 1928) and has been subsequently emphasized by several other commissions (Irrigation Commission, 1972; National Commission on Agriculture, 1976), the real attempts to had to wait till 1982. These efforts initiated by Central Soil Salinity Research Institute (Rao *et al.*,1986), got further strength from Dutch collaboration in the form of Indo-Dutch project Pilot Area Drainage Research (INDP, 2002), Haryana Operational Pilot Project (HOPP, 2001), Rajasthan Agricultural Drainage Project (RAJAD, 1995).

Fig 5. *Area affected with waterlogged saline soils*

Intensive monitoring of soil salinity, water table, sedimentation in drains, effluent quality and its reuse, and crop yields have been undertaken for periods ranging from 3 to 12 years. These efforts documented in several research publications led to evolution of appropriate technology for reclamation of irrigated water logged saline lands in arid regions (Ambast *et al.* 2007; Gupta 2014). The emphasis in these efforts was to keep focus on economic and environmental aspects, unlike the drainage in humid regions, where technical design criteria was given importance. The philosophy and innovations are briefly discussed.

In areas affected by salinity, water logging and continuous use of imbalance chemical fertilizer and ingressment of sea water mainly results in accumulation of salt in the root zone, therefore, following additional interventions are required.

Subsurface Drainage

If the natural subsurface drainage is insufficient to carry the excess water, dissolved salts in the soil are accumulated near root zone due to rise in groundwater leading to poor root aeration and thereby affects adversely even germination crops. As such, it is necessary to install an artificial drainage system for the control of the groundwater table at a specified safe depth and also for flushing out the dissolved salt of the soil.

Bio-Drainage

In canal irrigated areas, due to seepage of water from the canal or in low lying areas with frequent flooding, water logging occurs which mainly led to increase in salinity/alkalinity. Mechanical measures to prevent waterlogging through surface and subsurface drainage methods have resulted in lowering water level and reclaiming salinity problem of the areas.

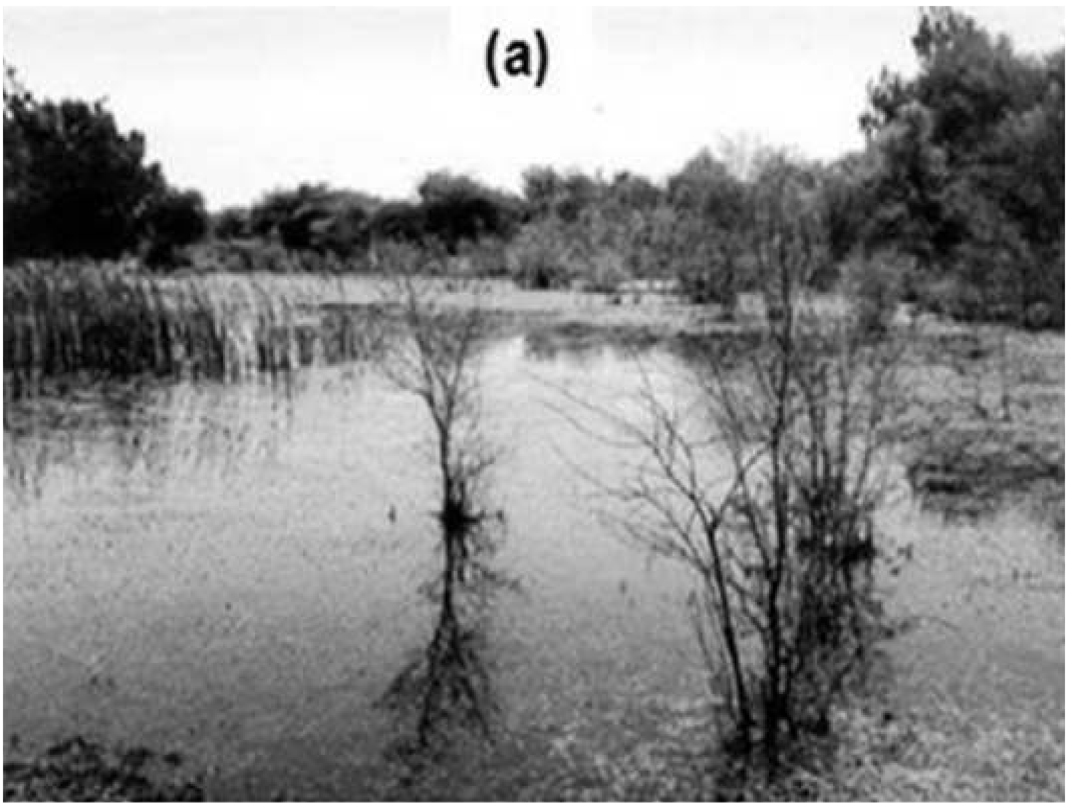

Fig 6 (a). *Inundated area caused by leakage alongside IGNP main irrigation canal*

Low cost, eco-friendly technology of raising bio-drainage plantations in waterlogged areas has also proved to be very successful in many cases and, therefore, such system need to be adopted in the areas having high salinity especially in the coastal saline areas.

Bio-drainage is the removal of groundwater by plants through evapotranspiration, which depends upon the plant species, plantation density, depth to water table and climate. Since many plants thrive well in saline root zone environment, it is believed that they may extract salt solutions and reduce subsoil salinity. However, whether the plant roots extract only the water, leaving the salts behind or whether it draws saline water and stores the salts in the plant is not well known.

Fig 6 (b). *Trees in background are the biodrainage system that dried-up the inundated areas along the main canal. (Source: FAO, 2002).*

The most common tree species recommended for biodrainage in Indian subcontinent and other parts of the world is *Eucalyptus* due to its high Evapo-Transpiration (ET) demand and adaptability to the varying soil, wet and salinity conditions. Tolerance to salinity and alkalinity with and without waterlogging provides added advantage for its adoption in establishing bio-drainage belt/ sole plantation crop.

Cramer *et al.* (1999) have, however, reported that *Casuarina glauca* could extract groundwater more than *Eucalyptus camaldulensis* planted at similar densities. They used naturally occurring isotope signatures of soil water, groundwater and sap flow measurement to determine tree water sources. Suitabile tree species for biodrainage in saline soils have been provided in Table 2.

Table 2. Suitability of tree species for saline soils (Source: Tomar and Gupta, 1999)

Tolerant (EC_e 25-35 dS/m)	*Tamarise troupii, T. artiaulata, Prosopis juliflora, Pithecellobium dulce, Parkinsonia aculeata, Acacia famesiana*
Moderately tolerant (EC_e 15-25 dS/m)	*Callistemon lanceolatus, Acacia nilotica, A. pennatula, A. tortilis, Casuarina glauca, C. obessa, C. equisetifolia, Eucalyptus camaldulensis, Leucaena leucocephala, Erescentia alata*
Moderately sensitive (EC_e 10-15 dS/m)	*Casuarina cunninghamiana, Eucalyptus tereticomis, Acacia auriculiformis, Guazuma ulmifolia, Leucanea shannonii, Samanea saman, Albizzia caribea, Senna atomeria, Ferminalia arjuna, Pongamia pinnata*
Sensitive (EC_e 7-10 dS/m)	*Syzgium cumimi, S. fruticosum, Tamarindus indica, Salix app., Acacia deanei, Albizia quachepela, Alelia herbertsmithi, Ceaselpimia eriostachya, C. velutina, Halmatoxylon brasiletto*

Filter Materials

Local filter material is placed around subsurface drains primarily to prevent inflow of soil into drains which may cause failure or to increase effective diameter or area of openings in the drains which increases water inflow rate. Thin sheets such as fiber glass or spun nylon and sand and gravel envelopes or other porous granular are generally used materials.

Maintenance of Drainage Systems

A subsurface drainage system normally requires little maintenance, these are properly designed. Outlet ditch should be kept free of the sediment and the tile outlet should be protected against erosion and undermining. Roots of nearby trees can also block subsurface drains for which shrubs and trees growing adjacent to a tile line should be removed. Weed growth must be controlled and the caving in of the sides requires continuous attention in order that entire drainage system continues to work efficiently.

ACIDIC SOILS

Acid soils are highly leached, generally poor in fertility and water holding capacity with pH value of less than 5.5. Such soils are having production potential but due to severe deficiencies of phosphorus, calcium, magnesium, molybdenum and toxicities of aluminum and iron, soil productivity decreases over the years.

General recommended package of practices for reclamation of acidic soils includes following measures:-

- *Field bunding, land shaping, construction of field channels/water harvesting structures, etc.*
- *Application of soil amendment (lime), at the rate of 2 to 4 quintals per ha in furrows depending on extent of acidity along with growing crops suiting to such soils to enhance productivity.*

- *Green manuring and its mulching into soil for increasing organic carbon in the soil along with use of F.Y.M.*
- *Growing of suitable crops (Pigeon pea, Soya bean, Groundnut, Lentil, Gram, Pea, Cotton, Maize, Sorghum, Wheat, Linseed and Mustard etc.) /horticultural/agro-forestry species including fuel and fodder plantation depending upon soil capabilities and slope conditions.*
- *Skill development for adoption of recommended package of practices on continuous basis to prevent recurrence of acidity in the soil.*

RECLAMATION OF COASTAL AREAS

Where offshore lands or tidal marshes are covered by shallow water and additional land is critically needed, the land can be reclaimed by construction of dikes roughly parallel to the shoreline, followed by drainage of the area between the dikes and the natural coastline. Where a sediment-laden stream can be diverted into the area between the dikes and the

Fig 7. *Recalmation and stabilization of coastal areas is a tedious task*

Occasionally, reclamation of tidal marshland can be accomplished by closing the mouth of tidal estuaries by dikes. Where the land surface is above low-tide level, a dewatering system based on tide gates which discharge water into the sea at low tide and automatically close to prevent re-entry of seawater at high tide may be used. In other instances, pumps have been used to lift water over the dikes. The use of pumps permits the reclamation of lands that are below low-tide level.

4 RECLAMATION OF MINE SPOILS

EXTENT OF MINING

India produces 95 minerals– 4 fuel-related minerals, 10 metallic minerals, 23 non-metallic minerals, 3 atomic minerals and 55 minor minerals (including building and other minerals). India is the 3rd largest producer of coal. Coal production in the country stood at 688.8 million tonnes in FY18. It stood at 576.00 million tonnes between April 2018 -March 2019. India ranks 4th in terms of iron ore production globally. In FY18, production of iron ore stood at 210 million tonnes. India has around 8 per cent of world's deposits of iron ore. India became the world's second largest crude steel producer in 2018 with an output of 106.5 million tonnes.

Fig 8. *Mining activities cause significant land degradation*

According to Ministry of Mines, India has the 7th largest bauxite reserves- around 2,908.85 million tonnes in FY17. Aluminium production stood at 0.92 million metric tonnes during Apr-June 2018 and is forecasted to grow to 3.33 million tonnes in FY20 (Press Information Bureau (PIB), Union Budget 2017-18).

However, the land under mining operations occupies a very small area in comparison to the total geographical area of the country. More than 80 % of the mineral production comes from open cast mines and therefore, one must add the quantity of overburden to that of the mineral production in order to assess the total amount of annual excavation in India's mining sector.

Surface mining accounts for 100 % production of iron ore, limestone, dolomite, bauxite, barites, fire clay, magnesite and lignite. In case of coal, open cast mining accounts for 5 % only at present, but it is increasing at the rate of 31 % of the coal surface mined area annually. Consequently, the mine excavation and pits are becoming larger and larger and waste dumps are growing in size.

Two main methods of mineral exploitation viz. open cast mining and underground mining produce scars and defacing surface features along with inversion of natural soil substratum sequence. This brings about superimposition of natural fertile soil by inactive and infertile materials.

Fig 9. *A view of underground mining*

Underground mining is the process of extracting minerals and ores buried beneath the surface whereas the mining operated from the surface and is entirely open is opencast mining. In opencast mining, the overlying soil is detached and the fragmented portions of rocks are stacked in the form of overburden dumps (Ghosh, 2002). The overburden dumps. i.e. the dump materials which are left over occupying large areas of land further degrades the soil quality and also loses its originality. The dump materials are usually fine and lose which become prone to wind. Thus, these lose particles spread over the surrounding fertile lands disturbing their natural quality. Also, the overdump materials are nutrient deficit therefore do not support plantation (Rai *et al.* 2009). The physical and chemical properties of the overdump differ from one site to the other due to their geological conditions (Lovesan *et al.* 1998).

Fig 10. *Open cast mining*

Hazardous activities start right from clear felling of vegetation for mining and allied activities which accentuate as the operations increase in intensity. Loss of soil productivity, biological diversity, health and environmental hazards due to air, water and noise pollution microclimatic changes etc. are some of the associated problems of the process (Banerjee and Gupta, 1996). Such areas are thus posing a great challenge for ecologists, biologists, agriculturists, engineers, soil scientist, and foresters as well who are invariably concerned about restoration of this disturbed ecosystem.

ENVIRONMENTAL HAZARDS DUE TO MINING

- Loss of Production

  It is quite evident that in open cast mining first of all, the surface cover i.e. vegetation is required to be removed or destroyed for extracting the minerals. It ultimately leads to total loss in production for all the times to come. This permanent loss in production is of great significance.

- Loss of surface/top-soil

  Next to suffer is the top productive layer of the soil. Nature normally takes thousands of years to produce a thin layer of this top-soil, which rather forms base for growth and development of plants. Open cast mining normally removes this top-soil in practically no time and it gets irretrievably lost.

- Surface Water Pollution

  Since the site is without any protective cover, the splashes of rain hit the exposed soils directly with full force. Some of the chemicals present in such exposed overburden get dissolved in the surface run-off, which then becomes unfit for human consumption, agriculture and for industrial uses as well. This polluted water after flowing down-streams, consequently affects the aquatic life at distant places.

- Ground Water Pollution

  The water which enters the solid profile after coming in contact with exposed toxic substances in the overburden areas, reaches the ground water table thus polluting the existing water table. This ground water however, happens to be the major source of drinking water and irrigation supply in the country and its treatment is extremely difficult. Practically, the ground water is utilized untreated and becomes the serious health hazard. The ground water table also gets considerably lowered in case of open cast mining.

- Ore Transportation

  This is a very serious environmental hazard whose extent and intensity is normally visible from miles away. A notorious example is that of quarry roads those cause immense damage to the vegetation, soil, drainage, agriculture, water quality and property. Besides this, the roads are laid out on very steep gradients in contravention to the laid down procedures/principles of mining or road construction. Such roads are often developed into drainage channels during rains.

- Sediment Production

  The exposed soil and overburdens are highly susceptible to the erosive action of the falling rain drops. As the material is loose, the erosive potential of these drops lead to the formation of rills and gullies on the exposed overburdens. Sediment from these quarries also get deposited on the agriculture and forest land and have been found blocking the streams and channels, thereby upsetting the normal drainage in the area.

RECLAMATION, ITS OBJECTIVES AND PLANNING

Mining leaves considerable area of land barren. After overburdening and dumping of top soil from the pit, the mined areas become steep, unstable and erosion prone, turning the area into a wasteland. This is why it is very important to restore the land back and there comes the process of reclamation. Reclamation, the last stage of mining process involves closing a mine and restoring back the land and water values. It involves re-contouring and re-vegetation of the mined area.

OBJECTIVES OF MINE RECLAMATION

According to Natural Resources Conservation Service (NRCS), U.S. Department of Agriculture (USDA) the main purpose of reclamation is:

- *Prevent negative impacts to soil, water, and air resources in and near mined areas*
- *Restoring the quality of soil to their pre-mining levels*
- *Improving and maintaining the functional quality*

Returning the land to a stable condition, preventing and future on-site or offsite environmental degradation, meeting the standard quality of air and water, maintain the ecosystem health and also preventing future hazards to public safety and welfare are few major reasons and importance of reclaiming the mined site.

Reclamation can further help in the following ways:

- *Conservation and restoration of ecosystem services*
- *Conservation and restoration of wildlife habitat*
- *Protection of water quality*
- *Recreational opportunities for mining communities*
- *Scientific and technical knowledge needed to protect and restore wildlife and aquatic habitats on mine lands*
- *To return landform structure, heterogeneity, and stability in the Project Site to conditions similar to those existing without the Project.*
- *To ensure ground and surface water quality and soil conditions provide the necessary conditions for terrestrial and aquatic life, including fish; and*
- *To re-establish productive land use that allows for wildlife habitat.*

RECLAMATION STRATEGIES

Both underground and opencast mines require reclamation, but the approaches are different. Reclamation activities for underground mines will typically require less above ground activity, but can necessitate extensive management to avoid drainage and flooding issues after mine closure. This management can involve techniques such as filling of excavated areas with mine spoil or fly ash and diverting or controlling the flow of groundwater to keep it from entering existing mine structures. Doing so prevents the risk of rising water becoming contaminated by dissolved metals and other substances and potentially being discharged into rivers and streams. More calcite or carbonates in the rock may help neutralizing acidic mine water which further allows metals to stay immobile.

Reclamation of opencast mines basically involves replacing the overburden which is removed or relocated to access buried coal layers. When excavated areas are built up, re-landscaping or recontouring is completed along with drainage control measures.

ECORESTORATION OF MINED AREAS

In mined areas, the overburden dumps exhibit completely modified ecological system and the mine spoil lack most of the physical, chemical, nutritional and biological characteristics of normal soils. Ecorestoration is a complex and long term process and requires a fundamental understanding of ecosystem structure and function including the process of primary as well as secondary succession (Connell and Slatyer 1977; Thomson *et al.* 1984; Givson *et al.*1985).

For taking up any biological reclamation programme, certain preparations are necessary in respect of the overburden dumps i.e. the dumps should be leveled, well compressed and made of desired shape. More the height of the dump more will be difficult to perform the reclamation operations because working on the slopes of such dumps is quite difficult and unsafe. Moreover, the erodibility of the overburden material especially in the rainy season become quite high when a big mass flows away with water and the steep slope adds to this phenomenon. Hence, a dump having more height is more instable. The height therefore, must not be kept more than 25 m and the slope of the dump should be kept low. This will not only lower down the rate of erosion but also facilitate the slope stabilization treatments.

The overburden material is very loose in nature as it consists of inert masses of sand, silt, boulders, pebbles etc. The height should not be more than 25 m and the slope of the dumps should be kept low. The Indian Bureau of Mines has reported the influence of the angle of dump slope on re-vegetation and erosion and suggested that slope angles steeper than 20° do not permit stable vegetation and are critical from erosion point of view.

During mining processes, original vegetation is completely stripped off and the soil profile sequences are disturbed. These abandoned sites witness natural vegetational succession at a slower rate than in areas where soil layer stays in the natural sequence (Bradshaw and Chadwick, 1980; Roberts *et al.*, 1981; Marrs *et al.*, 1981). Hence, before taking up any ecorestoration work, ecological survey of major vegetative association is most essential. Moreover, because of variability of chemical composition of ore deposits and its effect on associated geological formation, the study of soil overburdens is a prerequisite for any afforestation programme.

For the stabilization and nitrogen enrichment of the overburden spoils, the seeds and propagules of the identified species should be broadcasted at the initial stage. Because of the variety and specialized nature of the problems of industrial waste sites, any suitable afforestation project must be based on the results of trials carried out on the ground to be restored. Success of plantation and rehabilitation depends to a considerable extent on:

- *Status of site and its preparation*
- *Selection of suitable species*
- *Planting methodology*
- *Use of amendments*
- *Conservation of moisture*
- *Use of booster/fertilizer for initial nutrient support*
- *Initiation of microbial activity for bio-degradation of organic matter and*
- *Protection*

Soil provides the foundation for this process, so its composition and density directly affect the future stability of the restored plant community. Restoration of vegetation cover on overburden dumps can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to human beings (Wong, 2003). Reclamation strategies therefore, must address soil structure, soil fertility, microbe populations, top soil management and nutrient cycling in order to return the land as closely as possible to its pristine condition and continue as a self-sustaining ecosystem.

Soil particles those smaller than 2 mm are responsible for majority of water and nutrient holding capacity in the mine soils. Particles larger than 2 mm are referred to as "coarse fragments". Soils constituting high coarse fragments have larger pores that cannot hold enough plant available water against leaching to sustain vigorous growth over the summer months. The coarse fragment contents in a typical mine spoil vary (< 30- > 70%) due to differences in rock hardness, blasting techniques, and spoil handling.

Particle size distribution of mine soils is directly inherited from their parent rocks or spoils. The rock content in the surface of a reclaimed bench or outslopes will decrease overtime due to weathering of rock fragments to soil sized particles. It has been found that top soil materials, when they can be salvaged, are typically much lower in rock content than spoils and therefore have better water retention characteristics (Nicolau, 2002; Moreno-de las Heras *et al.*, 2008). Hu *et al.* (1992) are of the opinion that soil with stone content greater than 50% should be rated as poor quality. Stone content of coal mine overburden dumps has been reported to be as high as 80-85% (Maiti and Saxena, 1998).

Relative amount of sand (2.0 - 0.05 mm), silt (0.05 - 0.002 mm), and clay (< 0.002 mm) sized particles determine the texture of soil. Mine soils with sandy textures cannot hold as much water or nutrients as finer textured soils like loams and silts. The silts are finer textured soils and have a tendency to form surface crusts, often contain high level of soluble salts, and have a poor "tilth" or consistence.

The particle size distribution of the soils with loamy textures is generally ideal. Silt loam textures are common where spoils are dominated by siltstones (Ghose 2005). Ghose (2005) reported the maximum sand content of 66% and clay only 8.6% in mined soil. Singh *et al.* (2004) and Singh and Singh, (2006) also reported maximum content of sand (80%) and least content of clay (11%) at the Singrauli Coal field India.

Use of amendments becomes important and at times essential for growth of plants in mine tailing. Conservation of moisture can be achieved by the use of organic manures, soil working, mulching and use of synthetic hydroscopic materials. Application of fertilizer is of paramount importance for these wastes as they are mostly nutrient deficient. Generally microbial activity is lacking in mining and industrial wastes. Acidic spoils restrict microbial activity so that nitrogen release is slow. Forest soil spreading serves as source of mycorrhizal spores. Bio-fertilizer tested for tolerance of different types of spoils can also be used to initiate microbial activity. Planting of grasses in the initial stage also induce microbial activity and development of humus.

LANDSCAPING OF SITE PREPARATION ACTIVITIES

Status of site and its preparation includes easing of steep slope, terracing, leveling, bunding or ridge formation, spread of top soil, excavation of suitable size pits, gully plugging etc. Because of variability in chemical composition of ore deposits and its effects on associated geological formations the study of soil overburdens is a pre-requisite for any afforestation programme.

Landscaping or site preparation covers all the activities used for the removal of soils and overburden, disposal of wastes and the modification of disturbed land and waste disposal sites for achieving the reclamation of the area mined. It may include following activities:

- *Contouring of reshaping the back filled pit or dump of waste rock.*
- *Installation of an effective drainage and sediments control system.*
- *Covering of toxic waste, barren waste rock, tailing or any inhibition to plant with the previously stored top soil (up to a minimum of 30cm).*
- *Tillage operations.*
- *Prevention of erosion and excessive run off by grading and leveling of top dressed areas.*
- *Preparation of seed bed including ploughing and application of mulches.*
- *Putting, gouging and land imprinting.*

Thus, the site preparation has to be carried out with a view to improve the physical condition of the mined land, overburden and waste disposal area for eventual land use. In most of the cases, the ultimate land use may be in the form of revegetation by agriculture or forestry. However, it may be in the form of housing and industry, stadiums for sports, wild life habitats, water storage ponds, or pisiculture, etc.

Undulating surface of the dumps induce the gully formation. Also, on such surface it becomes difficult to take up an activity like planting. Hence, leveling of overburden dumps is a pre-requisite for any reclamation operation. It is also necessary to make the dump compact.

In the old dumps or tips are to be used for revegetation or agriculture, they are first graded to a gentle slop of less than 1:4 or 5 i.e. 12 to15 (Fig. 11). The graded surface is then covered with 15-30 cm thick layer of topsoil to ensure proper growth of vegetation. Compacted topsoils of old dumps are not suitable for plantation because of closing of voids due to compact and hard nature of the soil. These compacted soils are made suitable for plantation by deploying tillage method i.e. ripping, discing or scarifying.

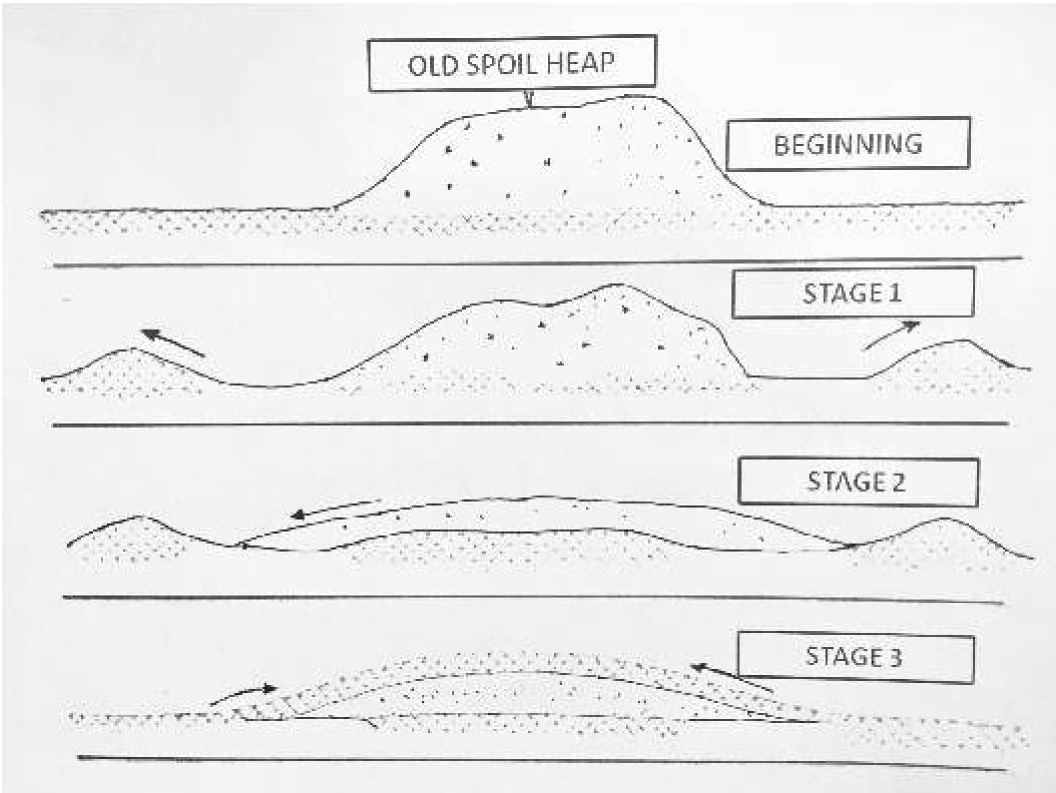

Fig 11. *Regrading of an old tip: Stripping and replacing*

In cases where the dumps height is more and the area is restricted the dumps may be vegetated in the existing position. In such cases, the dumps should be vegetated by grasses followed by plantation of trees. The tree may be planted by giving contour and drains all around the dumps and also on the top of the dumps after flattening them. However, in such cases arrangement for watering may be made in the beginning.

MANAGEMENT OF THE PRODUCTIVE MINE SPOIL

Rebuilding Soil Structure

The first soil component addressed during reclamation is the structure of the soil itself as it is replaced onto the reclamation site. Soil structure includes soil aggregation, or the way in which soil particles are held together, and the size of the particles comprising the layers at different depths. The degree to which soil is loosely constructed versus compacted can be altered during reclamation by the method of replacement adopted (Visser *et al.* 1984).

Using a tyre mounted mining machine (scrapers) than crawler mounted (dozers) to dig stored soil can minimize compaction. Transporting soil from the stockpile to the reclamation site on a conveyor belt with trundling action improves soil structure by breaking up massive aggregates. As smaller aggregates continue to tumble, they tend to acquire an agglomerative skin of fine particles, which promotes loose soil structure. Loosely constructed, or "fritted", subsoil is very important to plant root systems.

The extent of the root system determines a plant's ability to maximize its surface area and access a greater volume of water and soil nutrients. Plants grown in fritted subsoil have root patterns with extensive vertical and lateral penetration. Rock contents in the surface of a reclaimed bench or out-slope will decrease over time due to weathering of rock fragments to soil sized particles and therefore have better water retention characteristics. Gypsum ($CaSO_4.H_2O$) has traditionally been used to improve sodic media for plant growth (Richards 1954). It can be used to improve the structure of poorly structured sodic soils. Gypsum is normally incorporated into soil at about 5-10 tonnes/ha.

Application of gypsum results in replacement of sodium with calcium on the soil exchange surfaces, which can improve the soil structure, reduce surface crusting and increase water infiltration. It may also reduce the pH of sodic soils (soil with pH > 8.5) (Ghose 2005). An exchangeable sodium proportion of greater than 6% can indicate an unstable soil structure.

Management of Soil pH

A mine soil pH range in the range of 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses (Gitt and Dollhopf 1991; Gould *et al.* 1996). Maiti and Ghose (2005) reported that the pH vary from 4.9 to 5.3 in a coal mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area in the Ranchi district of Jharkhand State of India and thus indicated the acidic nature of the dumps. This acidic nature arose due to the geology of the rock presented in the area. It has been reported earlier that at pH less than 5, along with Fe, the bioavailability of toxic metal such as nickel, lead and cadmium also increases (Maiti, 2003).

Acidic mine soils can be effectively neutralized once they have been again spread at the reclamation site by applying either cement kiln dust (CaO) or limestone ($CaCO_3$). Lime application rates must account for both past and future pyrite oxidation in order to maintain neutral soil pH levels over time. Lime addition is a common method to decrease the heavy metal mobility in soils and their accumulation in the plant as it increases the p of soil. Plants like *Gravellia robusta*, can be planted at acidic dumps (pH 3.6-3.9), which increases the soil pH (Gitt and Dollhopf 1991). Organic amendments such as woodchips, composted green waste or manure, biosolids etc also increases the soil pH, in addition improves soil structure, water holding capacity, cation exchange capacity, provide a slow-release fertilizer and serve as a microbial inoculum (Tordoff *et al.* 2000; Jordan *et al.* 2002).

Increase soil fertility

The long term productivity of the plant/soil system is dependent upon several major factors:

- accumulation of soil organic matter and N;
- maintaining N-fixing legumes in the sand; and
- establishment of an organic-P pool and avoidance of P-fixation (Daniels 1999; Ghose 2005).

The three major macronutrients, namely nitrogen, phosphorus and potassium are generally found to be deficient in overburden dumps (Coppin and Bradshaw 1982; Sheoran *et al.* 2008). All newly created mine soils, and many older ones, will require significant fertilizer element applications for the establishment and maintenance of any plant community.

Majority of N needed to supply plant/soil community comes from N-fixation and subsequent mineralization of organically combined N. Therefore, maintenance of a vigorous legume component within the plant community is critical for reclamation success. Most mine soils do not contain native populations of the essential N-fixing *Rhizobium* bacteria those enable legumes to capture atmospheric N, so care must be taken to carefully inoculate all legume seeds used in new plantings. Since N is primarily combined in organic matter in soils, the addition of organic amendments to the soil can greatly enhance total soil N and its availability over time. Sewage sludge has been shown to be an effective mine soil amendment in numerous studies, but it may not always be available in sufficient quantities for use on remote sites.

Large fertilizer applications of P during reclamation will insure that sufficient P will be available over several years to support plant growth and to build the organic-P pool. Some P will also become available to the plant community as native calcium phosphates in the rocks decompose, but this P is not sufficient to meet the needs of a vigorous plant community. Some species, particularly from the family Protease, are reported to be adversely affected by application of P-fertilizers. These adverse affects are likely to be seen principally on sandy soils, and are less likely to occur on finer soils with a greater capacity to adsorb P.

The maintenance of plant available phosphorus (P) in mine soils over time is hindered by two factors: (i) fresh mine spoils are generally low in readily plant available (water soluble) P; (ii) as mine soils weather and oxidize they become enriched in Fe-oxides that adsorb water soluble P which is then "fixed" into unavailable forms. The tendency of mine soils to fix P increases over time. Because organic bound P is not subject to P-fixation, it is critical to establish and build an organic-P reservoir in the soil to supply long-term plant needs through P-mineralization.

Areas reclaimed for agriculture or other intensive use will normally require maintenance of the fertilizer programmed. There are also certain amendments which have shown promise for improving spoil as a plant growth medium. Saw dust has been shown to increase the survival rates of certain trees, forbs and shrubs (Uresk and Yamamoto 1986). Smith *et al.* (1985) observed that the addition of woodchips to bare spoils was second only to topsoil application for increasing plant establishing and their growth. Gitt and Dollhopf (1991) observed similar results when wood residue had been used as a spoil amendment. Amendment with wood residue with N increases the effects of fertilizers such as N, P, K or gypsum while amendments with gypsum increases the level of soluble salts (Voorhees and Uresk 1990; Sheoran *et al.* 2009).

Organic matter is the major source of nutrients such as nitrogen, and available P and K in unfertilized soils (Donahue *et al.* 1990). A level of organic carbon greater than 0.75% indicates good fertility (Ghosh *et al.* 1983). The level of organic carbon in overburden was found to be 0.35% to 0.85%. Organic carbon is positively correlated with available N and K and negatively correlated with Fe, Mn, Cu, and Zn (Maiti and Ghose 2005). Initial applications of fertilizers have shown to increase the specific numbers, plants co-density and growth rates of vegetation.

Type of fertilizer and its application rate will vary according to the site, soil type, and post mining land use (Kenny and Bremner 1966). Care to be taken while preparing fertilizer prescription and applying on the rehabilitated areas. Roots of seedling can be damaged if the fertilizer is placed too close to the plant (Schmidt 2003; Ghose 2005).

Local and state regulations and community attitudes frequently complicate the use of sewage wastes on disturbed lands. Sawdust and bark mulch are also helpful in increasing the initial mine soil organic matter contents but are generally low in N content. Saw dust and sewage sludge have been widely recognized as effective short-term fertilizers and sources of long term slow release nitrogen (Sydnor and Redente 2002; Munshower 1994; Hall 1984), besides serving as microbial inoculums. In addition, organic matter improves soil structure, reduces erosion, and increases infiltration. Furthermore, organic wastes can increase the water holding capacity of minespoils. Therefore, use of these materials as soil amendments will also require heavy fertilization with N- fertilizer.

RECHARGING SOIL MICROBES

Bacteria

In one study, amending replaced topsoil with hay and processed sewage sludge was more effective than topsoil inoculation in stimulating bacterial growth and activity, particularly for bacteria that oxidize ammonia (Lindemann *et al.* 1984). Bacteria present in the soil require a source of readily oxidizable carbon provided by the hay and sludge to fuel metabolic activity and stimulate nitrogen cycling. Topsoil contains carbon, but it is often in the form of coal or other humic material mixed during soil replacement and is not readily usable (Moynahan *et al.* 2002).

Mycorrhiza

Mycorrhizal propagule densities remain low immediately after reclamation on uninoculated sites, but re-establish themselves after couple of years (Williamson and Johnson 1991). This coincides with the appearance of host plants, such as tall fescue, that are more conducive to mycorrhizal colonization than those first appearing on the site (winter wheat) (Gould *et al.* 1996; Gould and Hendrix 1998).

Mycorrhizal propagules existing in the topsoil may be stimulated by the presence of suitable host plants. Lindemann *et al.* (1984) found that covering re-spread soils with 30 cm of topsoil (without mycorrhizal inoculum) also stimulated host colonization by mycorrhizal fungi whereas using hay, topsoil with inoculum, or sewage sludge had no effect. Sewage sludge may suppress mycorrhizal development by increasing the phosphorus available to host plants (Daft and Hacskaylo 1976).

Soil microbe population persists in stored soil and can be stimulated during reclamation by charging the system with a source of organic carbon or by adding suitable host plants. Many plant species, particularly those that are mycorrhizal (e.g. *Sericea lespedeza*), are able to draw P from difficultly available sources. Managing the microbial population in the rhizosphere - by using an inoculums consisting of a consortium of plant growth promoting rhizobacteria, mycorrhiza-helping bacteria, N-fixing rhizobacteria, and arbuscular mycorrhizal fungus as allied colonizers and biofertilizers; could provide plants with benefits crucial for ecosystem restoration. It is important to use indigenous arbuscular mycorrhizal fungus strains which are best adapted to actual soil and climatic conditions to produce site-specific arbuscular mycorrhizal fungus inocula (Mummey *et al.* 2002b; Khan 2004).

RE-ESTABLISHING NUTRIENT CYCLES

Nutrient cycling is very closely linked to soil microbe activity. It is the process by which carbon, nitrogen, and phosphorus are reused within an ecosystem due to the metabolic activity of plants and soil microbes. Carbon and nitrogen cycles in particular are disrupted as soil microbe populations decline and must be re-established during reclamation.

Carbon Cycle

Organic carbon fuels the metabolic activity of many soil microbes. Microbes obtain carbon through their symbiotic relationships with suitable host plants or from organic carbon available in the soil resulting from decomposition of plant and animal matter. Removal of topsoil from a mining site and mixing it with underlying soil considerably reduces the relative proportion of organic carbon (Visser *et al.* 1984). Little additional change in this proportion results from extended storage of soil.

Researchers frequently found the amount of organic carbon to be the limiting factor in stimulating microbial metabolic activity (Williamson and Johnson 1991). Amending soil with bark (Elkins *et al.* 1984) or fertilizing and planting ryegrass (Williamson and Johnson 1991) provides bacteria with enough organic carbon to stimulate metabolic activity, which can be measured by increased microbial carbon. Plant like *Dalbergia sissoo* improves the field moisture content (7%), pH (5.5), organic carbon (85%), and NPK. The increase in organic carbon level is due to the accumulation of leaf litter and its decomposition to form humus (Maiti and Ghose 2005).

Nitrogen Cycle

Soil organic matter has a very important influence on soil physical and chemical properties, on biological activities, and as a source of plant nutrients, especially nitrogen. Nitrogen in organic form is converted by microorganisms into ammonium (NH_4+). Under certain conditions specific microbes in the soil use ammonium N in the soil for energy and in doing so oxidize ammonium N(NH_4+) first into nitrite N(NO_2-) and then into nitrate N(NO_3-) which plants can then use to grow, a process referred to as nitrification. Some of that nitrogen is taken in by plants in that area, and some of it escapes into the atmosphere.

Free-floating atmospheric nitrogen can in turn be “fixed” by plants which will eventually be eaten or die, starting the cycle all over again. Amending the stockpiled soils with 15 cm topsoil during re-spreading stimulates nitrification and reduces leaching. Davies *et al.* (1995) reported that during the first two years after reclamation, nitrification rates in reclaimed sites were less than those in undisturbed sites, but approached levels similar to undisturbed sites after two years.

Nutrient recycling and availability on reclaimed sites is reflected in part by the rate of decomposition of plant material. Litter decomposition in mined land versus unmined land is often retarded during the initial months after reclamation (Lawrey 1977). Presence of heavy metals which reduce soil pH and lack of an existing litter layer create an unfavorable microclimate for soil microbes responsible for breaking down organic matter. Decomposition rates begin to equalize after six months suggesting increased microbial activity, but the initial death of recycled nutrients could impede establishment of new plants. Elkins *et al.* (1984) demonstrated that amending mine spoils with bark rather than topsoil significantly increases soil microbe activity and consequently decomposition rates but results in less available NO3 than in the spoil which is not amended. Oxidation of soil nitrogen to NO3 may be impeded by acidic soils or by the time length required by certain bacteria to become established.

TOP SOIL MANAGEMENT

The top soil is severely damaged if it is not mined out separately in the beginning with a view to replace it on the filled void surface area for reclamation in order to protect the primary root medium from contamination and erosion and hence its productivity (Kundu and Ghose 1998a, b). Sendlein *et al.* (1983), however, indicate that systematic handling and storage practice can protect the physical and chemical characteristics of top soil while in storage and also after it has been redistributed into the regarded area.

Ghose (2005) advised to avoid topsoil storage, especially in long term, for a time length by which the mine spoil can not maintain its sustainability for suitable plant growth without biological reclamation and also, maintenance of growth of aerobic bacteria. The following steps are; however, need to be followed for keeping the soil in good condition if storage is unavoidable:

- The surface of the stockpile should be thoroughly ripped with suitable sub-soiling machinery for the purpose of

- Relieving surface compaction caused by the passage of scrapers and other machines.
- Aeration of soil.
- Encouragement of deep-rooting plants by introduced vegetation.

- Following ripping, the heap should be cultivated with suitable low-maintenance species (like dwarf grasses) immediately to prevent erosion and gully formation.
- The surface vegetation should be actively maintained with seedling and weed control operations.

After final grading and before replacement of the top soil, slippage surface should be eliminated to promote root penetration. Top soil should be redistributed in a manner that achieve an approximate uniform and stable thickness consistent with the approved post mining land uses, contours, and surface water drainage system. It prevents excess compaction of top soil and protects it from wind and water erosion. It is of greater importance than any other factor in achieving successful reclamation of surface mined land.

The top soil must be uniformly redistributed in a manner which assures placement and compaction compatible with the needs of the species those will be used to restore the distributed area to its pre-mined potential (Ghose 2005). Nitrogen losses can be reduced by preventing the development of anaerobic conditions in the soil mound. Soil storage is for very short periods, periodically opening up and aerating the soil while stockpiled or permanently aerating, allowing drainage with a network of pipes and use of nitrification inhibitors after restoration are the operations that may in part ameliorate the problem (Davies *et al.* 1995).

Fig 12. *Backfilling of OB in exahusted pilot mine pit*

Vast majority of surface mines today employ some form of controlled overburden placement techniques and utilize top soil substitutes derived from blasted mine spoil materials. This occurs because natural soils tend to be thin, rocky, acidic, and infertile often making it impractical to salvage and re-spread topsoil on surface mined areas. The plant species used in active reclamation therefore are grown in mine spoils composed of freshly blasted overburden materials. The properties of these mine spoils are directly controlled by the physical and geochemical properties of the rock strata from which they are derived (Nagle *et al.* 1996; Daniels 1999).

Sydnor and Redente (2002) reported that topsoil if amended with addition of organic wastes increased above ground biomass influence trace element uptake. Even waste rock if properly neutralized, fertilized and amended with organic matter could also be directly revegetated.

Fig 13. *Top soil spreaded evenly on the backfilled quarry*

RE-VEGETATION AT ABANDONED MINE LAND

Vegetation has an important role in protecting the soil surface from erosion and allowing accumulation of fine particles (Tordoff *et al*. 2000; Conesa *et al.* 2007b). They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter, lower soil bulk density, and moderate soil pH and bring mineral nutrients to the surface and accumulate them in available form. Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients redeposit them on the soil surface in organic matter from which nutrients are much more readily available by microbial breakdown (Li 2006; Conesa *et al.* 2007a; Mendez and Maier 2008a).

If overburden spoils of different age series be examined it will be observed that ground flora are coming up naturally and increase in the number of species is a function of the age of the overburdens (Banerjee and Gupta 1996). A majority of species is recruited from the very beginning of succession and most of the species present in the newer sites are also present in the oldest mine spoils. Herbs and grasses are the major contributors to natural revegetator. Only few species participates in community formation as dominants or co-dominants.

Fig 14. *Establishment of plantation on OB dump*

The revegetation of eroded ecosystems must be carried out with plants selected on the basis of their ability to survive and regenerate or reproduce under severe conditions provided both by the nature of the dump material, the exposed situation on the dump surface and on their ability to stabilize the soil structure (Madejon *et al.* 2006). Normal practice for revegetation is to choose drought-resistant, fast growing crops or fodder which can grow in nutrient deficient soils. Selected plants should be easy to establish, grow quickly, and have dense canopies and root systems. In certain areas, the main factor in preventing vegetation is acidity. Plants must be tolerant of metal contaminants for such sites (Caravaca *et al.* 2002; Mendez and Maier 2008b).

Trees can potentially improve soils through numerous processes, including - maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below and reach of roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve physical properties, reduce soil acidity and improve soil biological activity. Also, new self-sustaining top soils are created by trees. Plant litter and root exudates provide nutrient-cycling to soil (Pulford and Watson 2003; Coates 2005; Padmavathiamma and Li 2007; Mertens *et al.* 2007).

The initial vegetation efforts must establish the building blocks for a self-sustaining system so that successive processes lead to the desired vegetation complex. The best time to establish vegetation is determined by the seasonal distribution and reliability of rainfall. All preparatory work must be completed before time when seeds are most likely to experience the conditions, which are needed for germination and survival, that is, reliable rainfall and suitable temperature.

Fig 15. *Successful reclamation of mined out areas*

Fig 16. *Biodiversity park developed on a coal mine site*

GENERAL CHOICE OF SPECIES

Species trial for comparative suitability of different species, use of amendments, fertilizer trial for boosting growth and higher biomass production etc are also equally important and need to be investigated in detail. Selection of species should be site specific and may include grasses, herbs, shrubs and tree species. In case of dumps from open cast and / or underground mines and industrial wastes, species should be planted step wise beginning with less exacting to higher plants in order of succession. Native vegetation of the locality should be preferred over others.

Grasses

Grasses are drought tolerant and can colonize fast in nutrient poor soil due to the presence of fibrous root they can reduce soil erosion as they are the best soil binders. Grasses are considered as a nurse crop for an early vegetation purpose. Grasses have both positive and negative effects on mine lands. They are frequently needed to stabilize soils but they may compete with woody regeneration. Grasses, particularly C_4 ones, can offer superior tolerance to drought, low soil nutrients and other climatic stresses. Roots of grasses are fibrous that can slow erosion and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. The initial cover must allow the development of diverse selfsustaining plant communities (Shu *et al.* 2002; Singh *et al.* 2002; Hao *et al.* 2004).

Leguminous plants/trees

On mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation (Yang *et al.* 2003; Song *et al.* 2004). An alternative approach might be to introduce legumes and other nitrogen-fixing species. Nitrogen fixing species have a dramatic effect on soil fertility through production of readily decomposable nutrient rich litter and turnover of fine roots and nodules.

Mineralization of N-rich litter from these species allow substantial transfer to companion species and subsequent cycling, thus enabling the development of a self-sustaining ecosystem (Zhang *et al.* 2001). Singh *et al.* (2002) reported that native leguminous species show greater improvement in soil fertility parameters in comparison to native non-leguminous species. Also, native legumes are more efficient in bringing out differences in soil properties than exotic legumes in the short term.

The legumes play an important role in increasing the soil nitrogen for they have symbiotic nitrogen fixing bacteria called as Rhizobia within the nodules in their roots which produce nitrogen compounds that help the plants to grow. When the plant dies, fixed nitrogen is released which will then made available to other plants and this helps in fertilizing the plants.

Native Species

Role of exotic or native species in reclamation needs careful consideration as newly introduced exotic species may become pests in other situations. Therefore, candidate species for vegetation should be screened carefully to avoid becoming problematic weeds in relation to local to regional floristic. For artificial introduction, selection of species that are well adapted to the local environment should be emphasized. Indigenous species are preferable to exotics because they are most likely to fit into fully functional ecosystem and are climatically adapted (Li *et al.* 2003; Chaney *et al.* 2007).

The native species which occur in the natural vegetation area are the best and appropriate candidate for use in the process of rehabilitation/restoration.

PROCUREMENT OF SEEDS

The seed quality has a direct effect on the economics of planting and also on the quality of future plants as well hence, procurement of good quality seeds is the first and foremost requirement for carrying out any plantation programme. Good quality seeds should have:

- *High physiological viability,*
- *High genetic quality i.e. they should be from a good quality mother tree and should also,*
- *Have capacity to produce healthy offspring.*

Besides this, planting of seedlings of even height should be another criterion, which can be accomplished through the sowing of even sized seeds. Bigger sized seeds normally show better performance. Thus, for restoration of any ecological and biological reclamation of mined areas, following programmes is required be followed:

- *Broadcasting of seeds and propagules of the pioneer species coming naturally on the overburdens.*
- *Selection of good quality seeds of the species suitable for plantation.*
- *Raising up of the seedlings of the selected species in nursery or in polybags of the suitable size.*

- *Lay out design of pits and pitting at the planting site must be carried out at least one month in advance before carrying out transplantation.*
- *Field planting to be done only with healthy and vigorously growing seedlings during rainy / winter season.*
- *The plants should be planted in the morning and only as many plants should be taken those can be planted on the same day.*
- *At the time of weeding, selected doses of fertilizers should be added around the plants to promote their growth. It should be ensured that there is sufficient moisture during and after manuring.*
- *In dry period leaf-litter mulch should be applied. The process will not only conserve moisture but after decomposition will also enrich the mine spoils.*
- *Weeding should be carried out in the second year only especially in the month of August and October and after this second dose of fertilizers can also be applied for obtaining the better results.*
- *Protection must be ensured.*

PROPAGATION AND PLANTATION

- Seed sowing

  Seed sowing is done just before onset of summer rains preferably in the month of May-June.

  - Drill seeding: Drill seeding places the seeds in soil at a prescribed depth. Seed should usually plant at a depth equal to twice their width.
  - Broadcasting seeding: Places the seeds on the soil surface. It is done with a hand. Combination of seed broadcast and drill seeding can be used in some situation.
  - Hydro seeding: Hydro seeding is a form of broadcast seeding which uses water as carrier to apply the seed. It is being successfully practiced to stabilize barren steep slope and fragile unstable surface. The system requires water, seed, fertilizer and mulch which are applied on the surface in the form of fine spray.

- Planting

  Planting can be done by various means:

  - Seedlings: Seedling planting is most often used to establish trees, or shrub species. Only those species that are difficult to establish from seed are transplanted.
  - Stem cutting: Many species like *Vitex negundo* can be propagated by stem cutting.
  - Bulbils: Species such as *Agave* can be propagated through bulbils.
  - Slip/culms/clumps/rootstock: The species such as grasses can be planted through slips, culms, clumps, rootstock etc.

WATER HARVESTING

Water harvesting is not possible in the steep slopes. The next alternative is to increase the infiltration rate by reducing the surface runoff. Freshly graded sites with little or no vegetation cover will have greater surface runoff and erosion problems than well vegetated areas. The amount of runoff depends on several factors: steepness, the length of slope, amount of rainfall and its duration and the soil infiltration capacity.

Scarifying and roughening the surface will increase the infiltration rate. Deep ripping to 0.8 m at 1 m centres in useful on sites where there has been consolidation due to passage of machinery.

Benches or terraces, often recommended for stability purpose will reduce the length of slope and improve access to long slopes for hydroseeding machines etc. Continuous contour trenches across the slope of the overburdens will be very much useful to check surface runoff and increase the infiltration rate. Strip plantation with selected species and grasses will further improve the infiltration. Ridging and furrowing along the contour at 1.5-5 m intervals will increase the infiltration and soil water storage.

Diversion ditches and grassed waterways are a permanent way of intercepting runoff. Contour ditches should be placed at 20 m intervals on mild slopes and 5 m intervals on very steep slopes. The ditches can be grassed to reduce water erosion. Grasses like *Saccharum spontaneum* and *Saccharum munja* will be useful and the species were frequently observed in the overburden and mined out areas. Species like *Altemanthera ficoides* may also be useful to check water erosion.

5 ECO-FRIENDLY MINING

Increased environmental awareness has led to acceptance that future land-use via restoration be examined prior to the start of mining. Problem areas from the past emphasize that adequate pre-planning can avoid or mitigate further extremes. Integration of rehabilitation strategies with mining plan may speed restoration and reduce total cost. Extraction of ores, separation of overburdens, disposal of spoils and road alignments can all be planned so that post mining topography, drainage and surface materials will accord with the future land use of the worked area.

Vegetation establishment will play a key role in all aspects of the landscape planning. Its major functions will be screening, stabilizing slopes and erosion control, improving soil conditions and structure, aesthetic value and most importantly, the provision of productive after use. Microbial symbiosis has been recognized as an important tool in promoting growth by boosting nutrient uptake and utilizing and fixing atmospheric nitrogen in root nodules.

Vesicular Arbuscular Mycorrhizae (VAM) is known to be associated with many plant species. The fungi mobilize soil phosphorus and make it available to the plants. In addition to it, these are phosphate solubilizing fungi which convert insoluble phosphate to plant available form. However, the ability of VAM fungi to associate with plants is rapidly depleted by top soil disturbance and stockpiling. This often results in low levels of infection in the early years of rehabilitation. Similarly, only limited numbers of ectomycorrhizal fungi species have been seen in young rehabilitation. As a result some species may not recolonize rehabilitated areas until specific mycorrhiza have recolonized. To conserve mycorrhizal inoculum, top soils should be direct returned where ever possible and when stockpiling is unavoidable, the piles should be low and revegetated as soon as possible. An actinomycete of the genus Frankia forms nodules with the capacity to fix nitrogen on the roots of species from genera *Casuarina* and *Allocasuarina*. These genera are often included in revegetation programme.

The modern approach to reclamation depends on an interpretation of the whole ecology of a site and its intended after use. It is important to aim at a level of environmental improvement which fits in with the proposed after use and is economically feasible and to select the ecologically appropriate plant species. Particular attention must be paid to special biological processes which restore soil fertility.

The various techniques for waste disposal include utilization of overburden and mine waste by back filling to help in reclamation, restoration and rehabilitation of the terrain without affecting the drainage and water regimes. If considered suitable, the waste may be used as road metal and construction aggregates after crushing to proper size. The dump must be properly graded and terraced with contour drainage as necessary Terracing of dumps must be accompanied by stabilization of the slopes and terraces with proper vegetation. The distance between terraces will, however, depend upon the degree of slope and slope length. Higher the degree of slope, closer will be the distance between the terraces.

An action plan for minimizing adverse environmental impacts from the proposed mining activity should be prepared. The important aspects to be taken into consideration during various phases are:

PRE-OPERATIONAL PHASE

Vegetational barriers shall be raised along the contour in the hilly areas for the prevention of soil erosion and for arresting mine wash. The banks of streams in the mining area should be intensively vegetated to prevent the discharge of sediments into the streams. The area cleared should always be the lease necessary for safe operation of the mine. When the rehabilitation objective is to restore the original ecosystem, the optimum time for clearing may be determined by the time when the important plant species set seed.

OPERATIONAL PHASE

Top soil is often the most important factor in successful rehabilitation, particularly where the objective is to restore a native ecosystem. It should be retained for subsequent rehabilitation. The top soil contains the majority of the seed and other plant propagules, soil microorganisms, organic matter and much of the more labile plant nutrients and its removal and return as a thin layer on the surface will maximize the contribution of these seeds to the post mining flora. Wherever possible the top soil should be immediately replaced on an area where the landform reconstruction is complete.

POST-OPERATIONAL PHASE

Once the mining is over, the land should be rehabilitated immediately for productive uses like agriculture, forestry, pisciculture, recreation etc. The physical and chemical properties of the spoils should be thoroughly investigated prior to rehabilitation. The following are the techniques which can be considered to improve the ability to support plant growth in the long term.

FACTORS THAT ENSURE SUCCESS OF RECLAMATION

- ### Pre-mining Bench-mark Survey

  This is an effective implementation strategy based on the geological and ecological surveys of the mining site prior to mining operations. It may even include the contour of the site, ground water acquifers and surface drainage patterns. Overburden if any to be generated, must be analysed for pH, acid base balance and also for heavy metals like Fe, Mn, Al etc.

  Complete analysis of over burden in-fact help in suggesting the soil characteristics ultimately, leading to a better and more suitable selection of species for re-vegetating the site. Ecological survey must include the major vegetative associations alongwith assessment of chemical and biological characteristics of streams etc.

  This bench-mark information will prove an asset in re-establishing the productivity of the site. Wherever possible, seeds, rhizomes, bulbs etc of the pioneering species should be collected and preserved so that once the mining operations stop these can be used immediately for ameliorating the site through broadcast seeding/ propagation to provide immediate green look to the area.

- ### Site Preparation

  Reclamation in the past was not getting much importance and hence, only partial or no back filling was undertaken after surface mining. However, now most of the countries regulations require that different horizons be segregated and replaced in the same order as removed during mining operation. Mining company has to leave land approximately to original contour wherever restoration plans requires them to do so. With the enactment of recent environmental laws in our country, it is hoped that in near future miner will take up necessary initiatives towards reclamation of the mined out sites.

- ### Restoration of the Site-ecosystem Approach

  Legislations and regulations of many countries require that productivity of the land be returned to the pre-mining conditions. These regulations further make it obligatory on the part of miners that the natural vegetative communities that existed on the site prior to mining must be re-established on the site. This will help in restoration of completely natural rather pre-mining eco-system comprising of vegetation, wildlife, microbial flora and fauna etc.

- Re-vegetation Practices

  The establishment of vegetation on abandoned, on active mine sites as well as on refuge heaps is rather quite difficult because of altered pH, lack of organic matter, coarse rock fragments and many other adverse biological and chemical factors. A package of practices interacting both through biological and mechanical measures -according to the local requirements- only can make a successful headway.

  A variety of trees, shrubs and grass species can be tried on these sites with varying degrees of success. Although in most of the reclamation projects stress is given to local species yet in some of the cases depending upon the site, climate and dump characteristics, exotic species are also being tried and have been found successful also.

- Needs of the Local People and Social-forestry

  Mining operations definitely disturb the local populations. In most of the cases, either local population is shifted by the company or they are deprived of their day to day requirements of fuel, fodder, fibre, cottage industry, medicines and many other products of pre-mining conditions/ecosystem.

  While taking up any reclamation programme, it must be clearly borne in mind that whatever final use the land is going to be put should be in favour of local population, their requirements of day to day use materials should be given top priority. Hence a comprehensive plan should be prepared in consultation with the local folk.

  To summarize, the points/activities those are essentially required to be taken into consideration during implementation of different phases of mining are:

  - *Preparation of eco-restoration/re-habilitation plan prior to the commencement of mining.*
  - *Minimization of the area to be cleared for mining and its associated activities otherwise necessary for the safe operation of mining.*
  - *Selection of suitable site for storing of top-soil and dumping up of the waste materials.*
  - *Determination of optimum time for clearing the land.*
  - *The rate of re-habilitation should be similar to the rate of mining.*
  - *The land disturbed by mining should be reshaped so that it is stable, adequately drained and suitable for the desired long-term land use.*
  - *Natural drainage patterns disrupted by mining should be reinstated wherever possible.*
  - *The potential of erosion by wind and water during and following mining should be minimized.*
  - *The spreading of the cleared vegetation on disturbed areas should be considered as mulch.*
  - *An Action Plan should be prepared to rehabilitate the people displaced by the mining activity.*

6 SPECIES FOR DIFFERENT RECLAMATION SCENARIOS

A crucial factor to the success of establishing vegetation is to identify suitable species (Sharma *et al.* 2000; Halofsky and McCormick; 2005b). Selection of suitable species is extremely important for the development of self-sustaining ecosystem. Selection of the species must be determined by the fact as to what will grow best in the particular soil and climate of the area. Some of the desirable features are; easy establishment, rapid early growth, longevity, size of the crown etc. Native plants are often tolerant of the local environmental conditions (Skeel and Gibson 1996; Siniscalco *et al.* 1998; Smith *et al.* 2005; Singh and Singh 2006; Wu *et al.* 2008).

Besides this, the shrubs and the species those are to be planted on the boundary should be unpalatable for the cattle and goats. The capacity to add leaf litter to the soil, nature of leaf litter as regards to its decomposition etc. is of equal importance. The following points should be kept in mind while selecting species for afforestation in mine spoils:

- *Should be adaptable to the site conditions.*
- *Should be from the group of pioneer species.*
- *Should preferably be of deciduous in nature so that maximum leaf-litter is obtained from the plant and the leaf should have the quality to decompose quickly.*
- *Should have long, deep root system.*
- *Should be able to fix atmospheric nitrogen and should have the ability to improve soil productivity.*
- *Should have tolerance for altered pH and toxicity of the site, if it is so.*
- *Should be from the indigenous origin.*
- *Should be capable to meet the requirement of local people in respect of fuel, fodder, fibre, fruit and small timber.*
- *The species selected should be able to attract birds, butterflies etc.*

In fact, no single species can fulfil all the above requirements and as such mixed plantation are advocated. The species suitability should be tested through pot culture experiments.

SPECIES SUITABLE FOR RECLAMATION IN TROPICAL AND SUBTROPICAL CLIMATIC REGIONS

Trees Species

Acacia catechu, Acacia nilotica, Albizia lebbeck, Albizia procera, Azadirachta indica, Bauhinia purpurea, Bombax ceiba, Butea monosperma, Cassia fistula, Dalbergia sissoo, Ficus infectoria, Ficus racemosa,, Ficus religiosa, Gmelina arborea, Hardwickia binata, Holoptelea integrifolia, Lagerstromia speciosa, Limonia acidissima, Madhuca indica, Melia azaderach, Moringa oleifera, Neolamarekia cadamba, Pithecelobium dulce, Pongamia pinnata, Syzygium cumini, Terminalia arjuna, Terminalia belerica, Toona ciliata, Trema politoria, Wendlandia exserta, Ziziphus mauritina

Horticulture Species

Aegle marmelos, Artocarpus heterophyllus, Embilica officinalis, Mangifera indica, Psidium gaujava

Shrubs Species

Agave sislana, Asparagus racemosus, Buddleia asiatica, Carissa opaca, Dodonaea viscosa, Indigofera tinctoria, Mimosa himalayana, Murraya koenigii, Rumex hastatus, Vitex negundo, Withania somnifera, Woodfordia fruticosa, Ziziphus nummularia

Grass and Sedge Species

Arundo donax, Cenchrus ciliaris, Cenchrus setigerus, Cymbopogon citratus, Cymbopogon martini, Cynodon dactylon, Eriophorum comosum, Panicum maximum, Pennisetum glaucum, Pennisetum pedicellatum, Pennisetum purpureum, Saccharum spontaneum

Bamboo Species

Bambusa bambos, Dendrocalamus strictus

Herbaceous Species

Crotalaria juncea, Mimosa pudica, Stylosanthes hamata, Trifolium repens

SPECIES SUITABLE FOR RECLAMATION IN TEMPERATE CLIMATIC REGIONS

Trees

Acer oblongum, Alnus nepalensis, Cupressus torulosa, Quercus leucotrichophora, Toona serrata, Ulmus spp.

Shrubs

Berberis aristata, Berberis asiatica, Berberis lycium, Coriaria nepalensis, Debregeasia hypoleuca, Debregeasia velutina, Desmodium tiliaefolium, Principia utilis, Rumex hastatus, Salix spp, Zanthoxylum alatum, Hypericum patulum

Grass Species

Cymbopogon spp, Chrysopogon fulvus, Arundo donax

Bamboo Species

Arundinaria falcata

Herbascious Species

Crotolaria juncea, Trifolium repens

IDENTIFIED SPECIES FOR DIFFRENT MINED AREAS

For coal mine overburden plantations *Pithecellobium dulce, Simaruba glauca, Acacia mangium, Cassia siamae, Dalbergia sissoo, Gmelina arborea* have been found appropriate. Similarly for Iron mine overburdens *Leucaena leucocephala, E. teritirornis, A procera, G. arborea, D. sissoo, Emblica officinalis, Dendrocalamus stricutus* are suitable.

Gmelina arborea, Eucalyptus camaldulensis, E. grandis, E. teritirornis, Acacia lenticularis and *Albizia procera* perform better at copper mined areas while *G. arborea, A. auriculiformis, Eucalyptus, A. camplycantha, Pongamia pinnata, D. strictus* are successful species at dolomite mined areas.

General prescriptions for suitable species for reclamation in different mined areas have been presented in the Table 3.

Table 3. List of Species suitable for Reclamation in different Mined Areas

S.No	Mine Area	Suitable Plants
1	Gypsum	*Prosporis cineraria (Khejri)* *Zizyphus mauratiana (Ber)*
2	Bentonite	*Maytenus emerginata*
3	Ochre	*Acacia nilotica* *Butea monospermam* *Euphorbia nerifobia (thor)*
4	Marble	*Prosporis cineraria, Prosopis juliflora*
	Limestone	*Prosopis juliflora, Terminalia arjuna, Ziziphus mauritiana, Ailanthus excelsa, Azadirachta indica, Butea monosperma, Madhuca lentifolia*
	Rock Phosphate	*Acacia catechu (Khair), Dalbergia sissoo, Eucalyptus hybrid*
5	Zinc tailings	*Ficus tomantosa, Prosopis juliflora, Azadirachta indica*
6	Lignite	*Terminalia arjuna, Dalbergia sissoo, Bamboo*
7	Bauxite	*Acacia auriculiformis, Pinus caribaca, Gravillea robusta* *E. camaldulensis, Grevellia pteridifolia, Pongamia pinnata*
8	Iron-Ore	*Delonix regia, Jacaranda, Bombax malabaricum, Samanea sama*
9	Salty lands	*Eucalyptus, Phoenix, Tamarix*
10	Area liable to inundation	*Acacia nilotica, Butea monosperma, Zixphus mauratiana*
11	Water logged Saline areas	*Eucalyptus robusts, E. rudis*

7 ICFRE'S EFFORTS IN RECLAMATION

BIO RECLAMATION THROUGH MICROBES (IFGTB COIMBATORE)

In Tamilnadu, Lime stone, Magnesite and Bauxite mining is undertaken in vast areas that creates degraded lands with mine spoils. Reclamation of these lands using conventional reclamation techniques of grading, resoiling and fertilizing mine spoils is a costlier strategy hence an alternative method has been developed by IFGTB Coimbatore.

Mine spoils lacks beneficial microbes as the top soil is removed during mining. Thus, instead of using top soil for planting activities the top soil properties such as beneficial microbes (bacteria and fungi) were used in reclamation of mine spoils. The sieved mine spoils of bauxite, magnesite and lime stone were collected and used as potting media for the selected tree seedlings under nursery conditions the beneficial microbes particularly Arbuscular mycorrhizal (AM) fungi, Plant Growth Promoting Rhizobacterias and Nitrogen fixing bacteria were isolated and inoculated to the selected tree seedlings of *Azadirachta indica, Acacia auriculiformis, Casuarina equisetifolia* and *Eucalyptus camaldulensis* and transplanted at Bauxite (1 ha). Magnesite (1 ha) and lime stone mine spoils (1 ha).

Based on the nursery experiments and field trials at mined out areas it was found that *A. indica, C. equisetifolia* and *E. camaldulensis* were suitable for reclamation of magnesite mine spoils along with beneficial microbes such as, AM fungi, Phosphobacterium and *Azospirillum*. Whereas *A. auriculiformis* with AM fungi + *Rhizobium, E. camaldulensis* with AM fungi + Phosphobacterium + *Azospirillum*, and *C. equisetifolia* with Frankia + AM fungi have been found for successful reclamation in Bauxite mined out areas. Similarly, *C. equisetfolia* with *Frankia* + AM fungi is more suitable for reclamation of lime stone mined out area as studied.

The technology has reduced the cost of top soil, manures and fertilizers. As the beneficial microbes inoculated with suitable tree seedlings in nursery there is no additional requirement for chemical fertilizers and manures. Ministry of Environment, Forests and Climate change, Govt. of India has applauded IFGTB for developing these reclamation techniques whereas mining companies, Associated Cement Company, Madukkari (lime stone), Coimbatore and Madras Aluminum Company Ltd (Bauxite) have received prestigious awards for reclamation of their mined out areas due to the efforts of IFGTB.

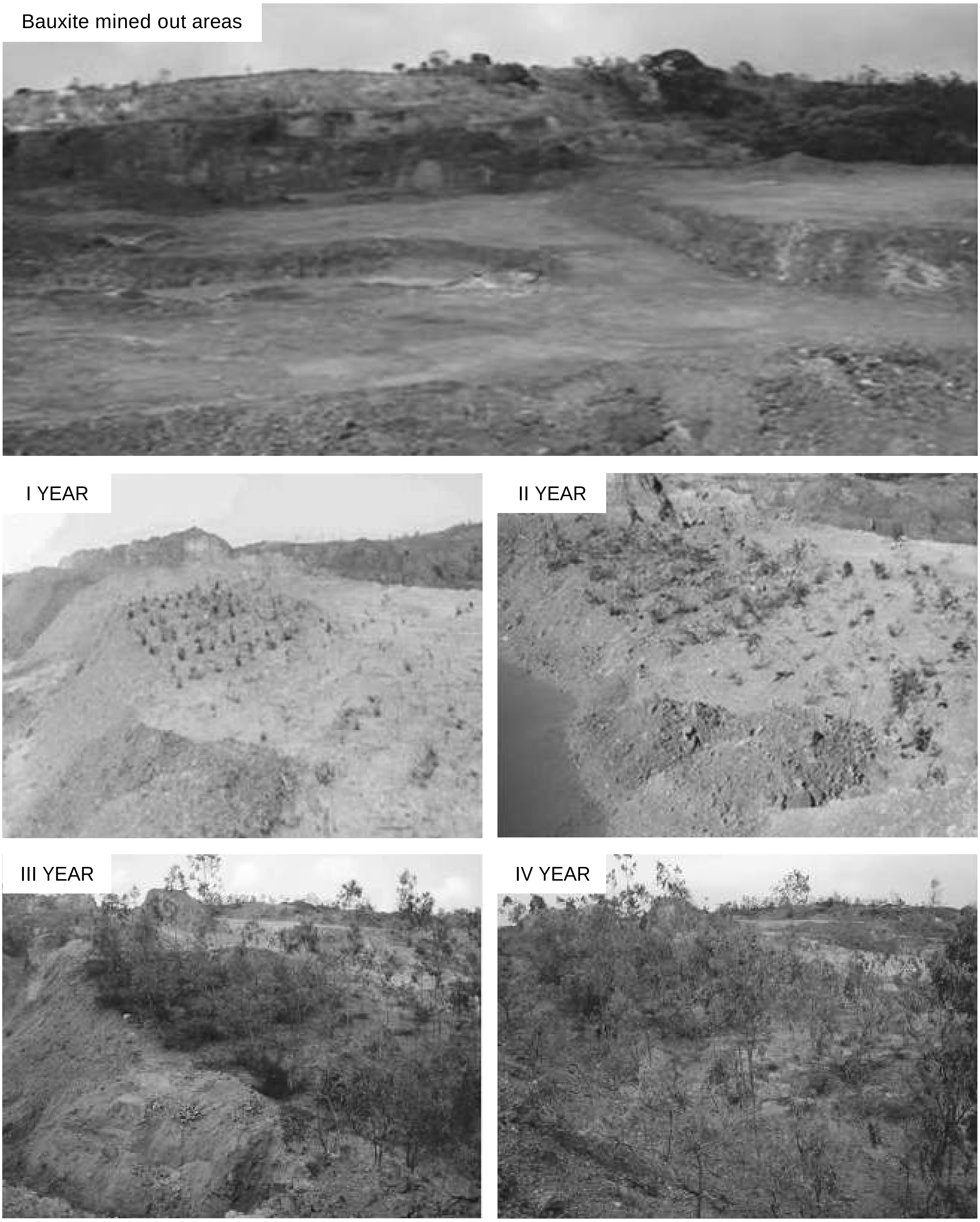

Fig 17. *Reclamation of mine spoils through beneficial microbes (bacteria and fungi)*

SPECIES TRIAL FOR LIMESTONE MINE RECLAMATION (HFRI SHIMLA)

Himalayas contain a large variety of commercially viable minerals and two main methods of their exploitation viz. open cast mining and underground mining are quite prevalent in the region. These exploitation processes ultimately produce scars and deface surface features along with inversion of natural soil-substratum sequence. The extraction of these minerals is bringing about superimposition of natural fertile soil by inactive and infertile materials.

Amongst various minerals occurring in Western Himalayas (Himachal Pradesh, Garhwal, and Kumaon), mining for limestone has been extensive in this region. Limestone deposits of Garhwal region are considered to be the best amongst various grades available in the country and hence, are the basic cause behind heavy extraction in the past. In Himachal Pradesh the area as leased out for limestone mining in the entire state is 19.10 km^2.

Studies were conducted during 2001 in polythene bags of size 12”x20” to evaluate the effect of different combinations of lime mine spoil and forest soil (1: 0, 5:1, 2:1,1:1,1:5 and 1:2 v/v) on performance of five tree species viz; *Bauhinia variegata, Robinia pseudoacacia, Eucalyptus hybrid, Grewia optiva* and *Toona ciliata*. The results show that combination of lime mine spoil-forest soil in the ratio of 1:5 or 1:2 (v/v) was the most effective with regard to survival, growth and biomass production parameters in all the five species. *Eucalyptus hybrid* gave maximum height, collar diameter, shoot dry weight, root dry weight and total biomass whereas, survival was observed highest in *Grewia optiva*. *Eucalyptus hybrid* was followed by *Bauhinia variegata, Grewia optiva, Robinia pseudoacacia* and *Toona ciliata* in terms of growth parameters.

In another investigation involving these very species in polythene bags of the size 12”x20” to evaluate the effect of different combinations of lime mine spoil- forest soil- farm yard manure (1:0:0, 4:1:1, 2:1:1, 1:1:1, 1:1:2, 1:2:1 v/v) the combination of lime mine spoil - forest soil - farmyard manure in the ratio of 1:1:2 or 1:2:1 (v/v) was found to be most effective with regard to survival, growth and biomass production parameters in all the five species. *Eucalyptus hybrid* gave maximum values for height, collar diameter, shoots dry weight, root dry weight and total biomass whereas, survival was observed highest in *Grewia optiva*. *Eucalyptus hybrid* was followed by *Bauhinia variegata, Grewia optiva, Robinia pseudoacacia* and *Toona ciliata* in terms of growth and biomass parameters.

Field trials to evaluate the performance of different tree species in limestone mine spoil during 1995 and 1996 were conducted at Baldwa and Hiyona limestone mine sites of Sirmour District of Himachal Pradesh. *Robinia pseudoacacia* showed better performance in comparison to other species at both the sites. In Baldwa site, *Robinia pseudoacacia* was followed by *Populus deltoides, Melia azadirach, Toona ciliata, Pinus roxburghii* and *Cedrus deodara* in term of height and diameter growth, whereas, at Hiyona, *Robinia pseudoacacia* was followed by *Populus deltoides, Bauhinia variegata, Toona ciliata, Quercus leucotrichophora* and *Pinus roxburghii*. Plantations in abandoned mined area were found to increase the organic carbon, available nitrogen, phosphorus and potassium contents.

The effect of forest soil (2.5 kg/pit) and mine spoil alone (control) on performance of three nitrogen fixing trees, viz., *Acacia mollissima, Leucaena leucocephala* and *Robinia pseudoacacia* in lime stone mine at Top-ki-Ber (district Solan, Himachal

Pradesh) revealed that *Robinia pseudoacacia* gave maximum survival (97.92 %), whereas, maximum (3.98 cm) height growth was observed in *Acacia mollissima*. Addition of forest soil positively influenced the survival, height and biomass of all the studied species, however, diameter and root: shoot ratio was more in mine spoil alone (control).

Studies to evaluate the changes in plant diversity and chemical properties of soil under the plantations of *Cupressus torulosa D. Don and Robinia pseudo-acacia* Linn. as raised on mine overburden areas near Paonta Sahib in Sirmour district of Himachal Pradesh were carried out during August, 2000. The number of ground flora species as recorded under *Cupressus torulosa* and *Robinia pseudo-acacia* plantation were 30m-2 and 42m^{-2} respectively.

On the basis of importance value index (IVI), *Oplismenus compositus* and *Eupatorium adenophorum* were found to be the dominant herbs under *Cupressus torulosa* and *Robinia pseudo-acacia* plantation respectively. In general, distribution of most of ground flora species was contiguous. Index of dominance was lower and index of diversity was higher for ground flora under plantations as compared to the exposed mine overburden area. The ground flora under *Robinia pseudo-acacia* has highest diversity index (4.223). The index of dissimilarity between plantations and exposed mine overburden area was high indicate remarkable degree of dissimilarity in ground flora species. However, there was plenty of similarity between two plantations as far as ground flora under them was concerned. Soil under plantations revealed better fertility status in comparison to exposed mine overburden area.

Changes as brought about in diversity of floral species and in chemical properties of soil under pure plantations of *Robinia pseudo-acacia* and mixed plantation raised over the mine overburden areas of Paonta Sahib in Sirmour district of Himachal Pradesh were studied during August, 2000. The number of ground flora species under *Robinia pseudo-acacia* and mixed plantation was 25 m^{-2} and 31m^{-2}, respectively. On the basis of importance value index (IVI), Peristrophe bicalyculata and Ageratum conyzoides were the dominant herbs under *Robinia pseudo-acacia* and mixed plantation respectively. Distribution pattern reflected that most of ground flora species was contiguous. Index of dominance was found to be lower and diversity index was recorded higher for ground flora under plantations while compared with exposed mine over burden area. The ground flora under mixed plantation however, showed the highest diversity index (4.168). Index of dissimilarity between plantations and exposed mine overburden area was high thereby indicating remarkable degree of dissimilarity in ground flora species.

Plenty of similarity between two plantations was however observed as far as ground flora growing under them was concerned. The chemical properties of soils as assessed under plantations showed improvement in fertility status while compared to expose mine overburden areas.

VARIED RECLAMATION EFFORTS (FRI DEHRADUN)

FRI Dehradun has developed and transferred various eco-restoration technologies based on the ecosystem approach in mined areas. Phosphate mine lands and lime stone mines in Mussoorie hills of Uttranchal in Doon valley were ecologically restored. Besides, this ecosystem approach made the sites capable of producing fuel and fodder on sustainable basis for the rural community. Presently, the model is being developed for Iron ore mines of Bihar and Orissa. The first uranium mine being decommissioned in the country has also given a project to this division for consolidation of uranium tailings through planting of appropriate species.

Ecological restoration of Lambidhar mine, Mussoorie

Lime stone, rock phospate Gypsum and dolomite were tundertaken for restoration works in mines in the dehradun Missoorie region. On the basis of three years trial, appropriate specie, planting techniques and soil moisture conservation methods were suggested.

Ecorestoration Studies in Uranium Mines

A project was taken up (December 2004-March 2011) in Uranium mines of Jaduguda (Jharkhand) to develop protocol for sustainable stabilization of radioactivity using native species of grass, herbaceous and shrub species. Objectives of the study were to identify the species which could prevent atmospheric dispersal of radioactive compound and also development of green belts to ameliorate the Uranium tailing sites.

The experiment was carried out in two phases- phase I and phases II. Overall the study revealed that seven species selected and identified show minimum concentration or below detective limit of the uptake of uranium by plants. This is also because of the fact that roots of selected species were confined to top 30 cm. layer of soil and do not penetrate the tailings. It is therefore concluded that these species have strongly influenced the physico-chemical properties of tailing capped soil in a short span of two years. Further, their roots were not penetrating the tailings in both experimental trials. All the species showed good survival on tailing pond as well as experimental containers.

Biostablization of Varunavat landslide in Uttarkashi

A study was carried out in Varunavat landslide of Uttarkashi, Uttarakhand during 2006-11. The main objective was to stabilize landslide area using bioengineering measures. Stabilization of exposed slide area was firstly completed by spreading of geojute followed by planting of different plant species ranging from grasses to shrubs and trees. Planting at site was done by various ways including seed sowing. After four years of stabilization it was recorded that the area has covered with dense and diverse vegetation.

Restoration of biodiversity in the hills of Kujapuri Siddhapeeth following Badrivan restoration approach (2004-07)

The objectives of this study were to rehabilitate degraded hills in and around the Kujapuri Siddhapeeth/Temple; to conserve the existing natural vegetation in and around the Kujapuri Siddhapeeth; and too assess ecological and socio-economic impacts of restoration.

The findings reveal that various native species such as *Arundinaria falcata, Aesculus indica, Cinnamomum tamala, Fraxinus micrantha, Abies pindrow, Myrica nagi, Cedrus deodara* etc. introduced in the hills of Kujapuri Siddhapeeth have been found successfully growing. Species of sacred importance such as *Ficus roxburghii, Ficus benghalensis, Aegel marmelos* have also been successfully introduced in the temple area.

Ecological stabilization of slopes at Koteshwar hydroelectric dam area (2007-10) THDC India Limited Tehri Garhwal, Uttarakhand

Slope stabilization of Koteshwar dam area of Tehra Hydro Development Corporation (THDC) was undertaken using appropriate soil working, soil and moisture conservation measures, seeding and planting of native plant species of forestry origin. Slope was covered with geo-grid. The total plants of various shrubs and grasses were planted/seeded with an average density of one lakh seedlings per hectare so as to provide a dense and luxuriant vegetation cover that can effectively check soil erosion from the steep slope.

Among various species planted, *Dodonaea viscosa, Rumex hastatus, Crotalaria sericea, Mimosa himalayana* have germinated and survived very well. Post stabilization ecological monitoring has clearly shown that diversity of plant particularly herbaceous has attained higher contribution in plant community and favour fast stabilization.

Chemical screening of species tolerant in lime kiln areas of Madhya Pradesh

Study revealed impact of lime kiln emission on biochemical responses of plants and physico-chemical characteristics of soil in lime kiln industrial area. Several tree species like *Acacia nilotica, Albizia procera, Pongamia pinnata, Azadirachta indica, Dalbergia sissoo, Butea monosperma, Mangifera indica, Citrus limon* and *Artocarpus heterophyllus etc.* were studied to find out the possible tolerance mechanism involved in developing tolerance against lime kiln tolerant and sensitive tree species against lime kiln pollutants were screened on the basis of Sensitivity Index. Quantitative variations in the invisible biochemical parameters of plants served as indicators of stress due to the air pollutants in lime kiln industrial area.

Plant growth strategy characterization, diversity and vegetational dynamics of rehabilitated and derelict mined ecosystems in Western Himalaya

Objectives of the study have been identification of plant strategies in relation to environmental resources and determine the structure and species composition to find out potential and realized niche of the species for suitability of ecorestoration of degraded sites. Temporal species richness and change of diversity in rehabilitated and unrehabilitated mined sites was also recorded.

Nutritionally poor sites at lower altitude were found to be colonized by the species like *Eriophorum comosum* (sedge), *Eupatorium glandulosum, Rumex hastatus, Buddleja asiatica* (shrubs) and *Wendlandia exserta* (tree). In middle and higher altitude, the nutritionally poor sites were dominantly colonized by *Eriophorum comosum, Chrysopogon fulvus, Cymbopogon distans, Pogonatherum* sp. (sedge and grasses), *Lespedeza sericea, Rumex hastatus, Coriaria nepalensis* (shrubs) Species such as *Rumex hastatus, Eriophorum comosum* have shown wide niche, occurring from nutritionally poor sites to nutritionally rich sites.

Road Map/ Action plan for plantation work (in pursuing the cause of forest trees) in BCCL mine areas, 2011

The road map for ecological restoration of coal mines of Bharat Coking Coal Limited in Dhanbad district has been prepared after a rapid appraisal of the extent of disturbance to biotic and abiotic components of the ecosystem. The mechanical measures included contour trenching bench terraces, brush fills, gully plugging etc, and biological measures such as broadcast seeding, hydroseeding, planting of seedlings and species suitable for overburdens, fringe forest areas and degraded forests vicinity to mining sites were identified for restoration. Suggestion for development of nursery was also a part of road map. Annual plan for execution of restoration activities for ten year period was also prepared alongwith monitoring mechanism.

Developing ecological restoration model in the mine spoils at Tetulmari under Sijua area of BCCL,mine, Dhanbad 2011-14.

The study developing restoration model in coal mine areas was carried out during 2011-2014 in about 8-10 ha areas at Tetulmari of Sijua area of BCCL, Dhanbad. The Various measures such as direct seeding, seed mixed soil balls, seedling plantating, stem cutting, bulbils, culm/slip planting were used during restoration process. Mulching on OB dumps was also done to enhance the moisture retention capacity of OB dumps.

The tree species planted at the site included *Albizia lebbeck, A. procera, Bauhinia variegata, Dalbergia sissoo, Pongamia pinnata, Azadirachta indica, Terminalia arjuna etc.* while *Vitex negundo, Dodonaea viscosa* as shurb and *Pennisetum purpureum, Arundo donax* as grass species were also used.

Dalbergia sissoo, Azadirachta indica, Emblica officinalis, Bauhinia purpurea and *Albizia* sp. were recorded to be highly successful species in restoration of coal mined OB dumps. Model restoration programme which has been developed is being replicated in other coal mined out areas of BCCL, Dhanbad. The restoration approach applied has been found to be very successful in enriching diversity of trees, shrubs and grasses in the project area.

Identification and Reclamation of 10 hectares of degraded land and biodiversity development at NCL, Singrauli 2014-17

The project with the aim to develop ecorestoration model and conservation of biodiversity has been executed in coal mined overburden dumps at Nighai and Krishnshilla of Singrauli Coalfields. To facilitate the growth and establishment of planted and natural species, soil quality amelioration by way of top soil spread and mulch material spreading was done. Various plant forms of multi uses were used during the process of restoration. These were planted by various ways i.e., seed broadcasting, seed mixed soil balls, root stock, culm, branch cutting and seedling.

Dalbergia sissoo, Gmelina arborea, Albizia lebbeck, Pongamia pinnata, Bauhinia variegata, Emblica officinalis, Neolamarckia cadamba, Pithecellobium dulce were found to be the most successful species both in respect to the survival and growth. Top soil spread in mined out areas has resulted a dense and diverse ground cover as compared to the site without top soil spread, indicated the importance of use of top soil in mined degraded areas. The model of restoration developed in coal mined area at Nighai and Krishnshilla is being replicated in other coal mined out areas of NCL, Singrauli.

Detailed ecological restoration study including assessment of site conditions of the mine and analysis of results of plantation work carried out during previous years in Jhingurda mine of NCL, Singrauli, 2014

The study was carried out in rehabilitated coal mined areas under different age series plantation or OB dumps as well as undisturbed natural forests. The study was carried out in relation to plant diversity, community structure, soil characteristic and micro flora species. The rehabilitated areas on OB dump ranging from 2 yrs to 28 years old. Most of the parameters such as silt, clay, porosity, moisture, organic carbon, available nitrogen were recorded highest in 28 years old rehabilted sites, which were found increasing over the years of rehabilitation.

As regard microflora there were 30 species of fungus. The diversity of soil fungi indicated that soil quality started improving due to rehabilitation of OB dumps. The occurrence of native plant species was also recorded maximum in

28 year old rehabilitated sites. In nutshell Bulk density was found to be reducing over the years of rehabilitation. pH value increased from 6.57 to 7.14 after 28 years of rehabilitation sites. Organic carbon (0.95% to 2.87%), available nitrogen (0.0125% to 0.02227%), available phosphorus (0.080% to 0.413%) and exchangeable potassium (0.0008% to 0.002%) have also found increased after 28 years of rehabilitation in coal mined overburden dumps of Jhingurda project areas of Northern Coal Fields Limited, Singrauli.

Ecological restoration study in coal mines of NCL, Singrauli, M.P. 2014-15

The project was undertaken with the objectives to ascertain the impact of rehabilitation on soil quality amelioration, vegetation development, microbial biomass and regeneration of planted species. The study was carried out under age series of rehabilitated areas in nine collieries of Northern Coalfields Limited, Singrauli. The age of rehabilitation area were as regard site quality amelioration under different tree plantations after 29 years, sand percentage was found to be reduced maximum from 84.67% to 69.33% in *Pongamia pinnata* and *Azadirachta indica* plantations, and silt percentage was found to be increased maximum from 13.33% in recent OB dumps to 24.67% in mixed plantation of *Prosopis juliflora* and *Holoptelea integrifolia*. Clay percentage, organic carbon, soil carbon density (tha-1) were recorded maximum under mixed plantation whereas available nitrogen content was maximum under *Dalbergia sissoo* plantation. Shrub and herbaceous species diversity was also recorded highest under mixed plantation.

Preparation of road map for ecological restoration works of their ten coal mines at Singrauli 2017-18

Northern Coalfields Limited (NCL), Singrauli assigned the task of preparation of road map for ecological restoration works of their ten coal mines at Singrauli in 2017. A detailed road map has been prepared and submitted in May 2018 suggesting various activities required for ecological restoration of coal mines These activities included the management of waste dumps through application of engineering measures, techniques for soil and moisture conservation. As a part of biological measures this included selection of species, methods of planting (Direct seed sowing, seed mix soil ball/slurry, hydro seeding, seedling planting), etc. Measures for the management of backfilled OB dump, haul and approach roads have also been s suggested in road map. Finally based on the survey and observations recorded in the OCPs areas, suggestions and recommendations for scientific dumping of OB dumps, terracing on OB dumps, application of soil and water conservation measures, preservation of top soil and its spread on OB dumps, development of green belt, management of haul and approach roads, use of native plant species in eco-restoration of OB dumps and backfilled areas, and avenue plantation in township areas are given in the road map. The thrust on implementation and monitoring of restoration works and capacity building are also discussed in the report.

Enhancement of biodiversity and its conservation in the ecological restoration site at Tetulmari (8.00 ha), Sijua area of BCCL, Dhanbad 2015-18

Ecological restoration followed by enhancement of biodiversity in the ecologically restored site under the project "Enhancement of biodiversity and its conservation in the ecological restoration site at Tetulmari (8.00 ha), Sijua area of BCCL, Dhanbad" has been carried out in 8ha coal mined OB dumps at Tetulmari, Sijua area of BCCL, Dhanbad.

The 8ha area has been restored and biodiversity enhancement has been done in mining site at Tetulmari, Sijua area of BCCL, Dhanbad. Nearly 6060 plant of different species of multiple uses were planted by various means such as seed sowing, seedling, planting, stem cutting, at the site. The site has been monitored for three years and time to time restoration activities has been taken up to restore the site .

Development of Ecorestoration Model for Iron Ore Mines of Bihar and Orissa (MOEF) 2001-2007

The project is of immense practical utility for the mine areas of Bihar and Orissa, where out of 47,797.00 hectares of mine lease area, nearly 11,500 hectares of the land area is under leases for iron ore alone. The objectives of the project was to develop ecological and economically viable restoration model for iron ore mines of Bihar and Orissa, which are spread over an area of 11,500.00 hectares. Ecorestoration model has been developed on the basis of detailed soil, vegetation and parent materials in relation to ecological and ethno- botanical information.

Ecological Succession in Restored Mines Lands

Ecological succession was studied in the rock phosphate mine at Maldeota, Dehra Dun. The study site is divided into the five plantation types namely Khair plantation type, Shisham plantation type, mixed plantation type, Natural plantation type, Pine plantation type. The maximum amount of phosphorous was recorded in Shisham plantation type and lowest was recorded in Pine plantation type.

The Magnesium content was highest in Pine plantation type and lowest in Shisham plantation type. Similarly, the amount of Potasium was highest in Natural plantation type and lowest in Shisham plantation type. The Calcium content was highest in Mixed plantation type and lowest in Shisham plantation type.

The dominant tree species in the khair plantation type is *Acacia catechu* while in shrubs *Lantana camara* was the most dominant species. In case of herbs, the most dominant species was *Bidens biternata.*

In Shisham plantation type the most dominant tree species was *Dalbergia sissoo* while in case of shrubs *Lantana camara* was the most dominant species. Similarly in case of herbs was *Bidens biternata* followed by *Murraya koenigii*.

In Mix plantation area the dominant tree species was *Adina cordifolia* followed by *Acacia catechu.* In Shrubs the most dominant species was *Lantana camara* while in case of herbs the dominant species was *Achyranthes aspera*.

In Natural plantation type the most dominant tree species was *Bauhinia variegata* while in shrubs *Adhatoda vasica* dominated the plantation type. In herbs the most dominated species was *Bidens biternata.*

In Pine plantation area the most dominant species the most dominated species was *Pinus roxburghii* while in shrubs the most dominated species was *Lantana camara* and in herbs the most dominated species was *Murraya koenigii*.

Ecorestoration Studies in Uranium Mines (BARC (2004-10))

Seven native plant species of forestry origin, viz. *Colebrookea oppositifolia, Dodonaea viscosa, Furcraea foetida, Imperata cylindrica, Jatropha gossypifolia, Pogostemon benghalense* and *Saccharum spontaneum* have been selected and identified to show minimum concentration or below detective limit of the uptake of uranium by plants.

This is also because of the fact that roots of selected species were confined to top 30 cm. layer of soil and do not penetrate the tailings. It is therefore concluded that these species have strongly influenced the physico- chemical properties of tailing capped soil in a short span of two years. Further, their roots were not penetrating the tailings in both experimental trials.

All the species showed good survival on tailing pond as well as experimental containers.These results are based on preliminary investigations of one and two year old plant trials, however further comprehensive studies are required to finally conclude.

RECLAMATION IN ARID REGION (AFRI JODHOUR AND OTHERS)

Rajasthan holding reserves for 44 major and 22 minor minerals and the only producer of garnet, jasper, selenite, wollastonite and zinc concentrates comes second after Jharkhand state as regards to mineral wealth. It is also the leading producer of calcite, lead concentrate, ball clay, fireclay, ochre, phosphorite, silver and steatite.

All the minerals except base metals (Pb, Zn and Cu, etc.) are raised from open cast mines. The important minerals are limestone, gypsum, rock¬phosphate, marble, soapstone, sandstone, calcite, dolomite, silicasand, garnet, mica, barytes, clays etc. with the increasing industrialisation the demand is also increasing year by year.

Mine spoils are becoming a source of land degradation although the area covered under such degradation is still negligible. One of the major constraints in rehabilitation of mine spoils in arid regions is the very poor status of plant nutrients in the overburden/ mine dump. Higher pH, and exchangeable sodium, magnesium, sulpher and phosphorus, as well as salinity-alkalinity build up are the other constraints in many mine spoils. Plenty of research has been done on various aspects of rehabilitation/restoration of mine dumped area in the state (Saxena *et al.* 1997; Gupta *et al.* 1998; Kumar *et al.* 1998; Sharma *et al.* 2000, 2001; Sinha *et al.* 2000; Rao and Tak 2002; Rao *et al.* 2002; Pandey *et al.* 2005).

Re-vegetating mine sites has been shown to increase infiltration, reduce runoff and improve soil water holding capacity (Loch and Orange 1997; Loch 2000a; Loch 2000b). Revegetation of the mine spoils is, therefore, very challenging. CAZRI attempted to revegetate limestone and gypsum mine spoil areas to the south and east of Jodhpur with some degree of success. Saxena *et al.* (1997) listed the suitable tree, shrub, and grass species for rehabilitation of different kinds of mine spoils. Development of micro-catchments with 5% slope to ensure run-off to single row of plants, and other soil conservation practices like ridge and furrow system and half-moon structures, helped to grow shrubs and grasses with about 90 per cent success (Gupta *et al.*, 1998).

The main chemical problems are the lack of nitrogen and phosphorus due to the lack of organic-matter content, low cation exchange capacity, and base saturation (Jim 2001). To overcome these challenges, addition of organic wastes is useful which will ultimately increase N fertility and stimulate microbial action (Singh et al. 2000; Wong 2003). Excavated sediment of ponds and tanks is an effective indigenous soil amendment practice in India. Pond silt is not only productive but also a seed bank for a variety of grasses, herbs, shrubs, and trees (Pandey 1996). Rehabilitation success to revegetate mine spoils in arid regions was achieved using a combination of *in-situ* rainwater harvesting, soil amendments, and establishment of trees, shrubs and grasses (Kumar *et al.* 1998; Sharma *et al.* 2000, 2001).

Fig 18. *Ecorehabiltation work by AFRI Jodhpur in arid region*

Some arbuscular mycorrhizal fungi (AM fungi) native to limestone mine spoils may play a critical role in rehabilitation of mine spoils. AM-fungi have positive role in improving the water and nutrient uptake and enabling the plants to withstand high temperatures (Kumar *et al.* 1998; Sharma *et al.* 2000; 2001). It should be noted here that the best practice should have been the safe storage of topsoil for reuse in restoration before mining commenced (Rate *et al.* 2004).

Direct seeding of native species has also been found to be a useful and cost-effective restoration method globally (Camargo *et al.* 2002; Parrotta *et al.* 1997; Parrotta and Knowles 1999; Pandey 1996; Singh *et al.* 2004). A useful approach is to include a set of selected indigenous herbs, grasses, shrubs and trees known as framework species because they help re-establish a basic forest structure that catalyses the recovery of biodiversity (Elliott *et al.* 2003). A study by Rao and Tarafdar (1998) indicates that *Prosopis juliflora, Salvadora oleoides* and *Cenchrus ciliaris* can grow well in mine spoils. *Salvadora oleoides, Colophospermum mopane* and *Pithecellobium dulce* have been noted to be calcium-loving plants, thus species can be useful for rehabilitation of gypsum mine spoil.

Direct sowing helps in enhancing biodiversity per unit area, perhaps because it accelerates natural plant succession processes, as the ground cover created by newly germinated seeds acts as a nurse crop and can trap air-borne seeds from the vicinity (Jha *et al.* 2000; Jha and Singh, 1993). Thus, multi-tier vegetation (i.e. vegetation assemblage layers of herbs, shrubs and trees with differential height profiles) can be effectively developed (Pandey 1996).

Other rehabilitation strategies include; soil ripping to reduce compaction (Ashby 1997), topsoil replacement including the seed bank (Holmes 2001), mycorrhizal inoculation (Caravaca *et al*. 2003) and many types of substrate amendment. However a study by Rao *et al.* (2000) in a limestone quarry indicates significantly lower microbial activity than in reference areas even after five years and suggest waiting some time for natural recovery before implementing management action.

RECLAMATION IN CENTRAL INDIA (TFRI JABALPUR)

Coal mines

A trial was conducted in the TFRI nursery with 57 species in poly-pots filled with a mixture of overburden spoil and compost (farm yard manure) in 1:1 proportion and performance was studied after 6 months. On the basis of survival and growth data 12 species (11 NFT and 1 non-NFT) were selected for field plantation. Most of the other species did not survive at all. Block (monoculture) plantation of eleven NFT species *(Acacia catechu, Acacia nilotica, Acacia leucophloea, Acacia mangium, Acacia auriculiformis, Acacia holosericia, Albizia lebbek, Albizia procera, Pongamia pinnata, Dalbergia sissoo and Pithecellobium dulce)* and one non-NFT species *(Gmelina arborea)* was raised in 13 ha of the dump material in Bisrampur colliery of Surguja district of Chhattisgarh state.

The overall performance of different species was assessed by working out a suitability index on the basis of mean height growth, mean collar diameter and biomass attained by the species after 8 years by giving 100 points to the highest value of each parameter and finding the total score of each species.

Shoot biomass of planted trees is an important consideration in selecting a species for revegetating the degraded land. After 8 years of plantation total biomass production was maximum in *A. mangium* (191.80 kg/tree) followed by *A. holosericia* (68.14 kg/tree), *D. sissoo* (51.99 kg/tree), *A. procera* (49.0 kg/tree) and *A. auriculiformis* (35.98 kg/tree). The suitability index was worked out on the basis of mean height growth, mean collar diameter and biomass attained by the species after 8 years. *A. mangium* obtained the highest score of 300 followed by *A. holoserecia* (240.63), *D. sissoo* (234.76), *A. procera* (214.92), *P. dulce* (186.20), *A. auriculiformis* (178.20) and *G. arborea* (170.46). Very poor score was observed in case of *A. nilotica* (84.79).

Table 4. Communities formed in coal mine spoils in plantations of different age.

Age	Community
After 1 year of plantation	Cassia - Xanthium - Argemone
After 2 years of plantation	Cassia - Xanthium - Eulaliopsis
After 4 years of plantation	Cassia - Xanthium - Hyptis
After 6 years of plantation	Cassia - Eulaliopsis - Xanthium
After 8 years of plantation	Cassia - Eulaliopsis - Hyptis

Tree species like *Azadirachta indica, Ficus bengalensis, Butea monosperma, Syzygium cuminii, Ziziphus jujuba* invaded in 6 and 8 years old plantation sites. Invasion of tree species is an indication of stabilization of the ecosystem in the process of succession. These five tree species are very common in natural forest community of the tropical region and may be considered as the early colonizing tree species in coal mine overburden of Bisrampur.

It is apparent that species growing as ground flora and also the planted species gradually modified the nutrient status of the inert overburden spoils through constant litter return and atmospheric nitrogen fixation.

Iron

Iron ore in India is produced in Singhbhum-Keonjhar, Sellary-Hospet, Saidadila and Dalli-Rajehra regions and does not have much of overburden except for some laterite and low grade ferruginous shales. The major part of Dalli-Rajehra was covered by mixed deciduous forest, dominated by *Tectona grandis* and *Shorea robusta. Boswellia serrata* and *Dendrocalamus strictus* overlapped as mixed forests. *Terminalia tomentosa* and *Lagerstroemia parviflora* were found present in appreciable quantity in nearby natural forests.

Laterites and lateritic soils, alluvial soils and red and yellow soils mainly occurred in this region and the texture of the soils varied from sandy loam to loam to fine textured clayey soils.

Among the selected sites, the largest family found was Poaceae with 16 species, followed by Fabaceae and Asteraceae with six species of each. Predominance of Poaceae and Asteraceae in mined lands has been reported earlier by Prasad and Pandey (1985), Russel (1985) and Jha and Singh (1990).

Shrubs like *Cassia tora* and *Calotropis procera* were present in all the sites. *Solanum surattense, Tephrosia purpurea* and *Tribulus terrestris* were also present in all the spoil sites except in 2 year old one. This shows that these species were better adapted to the spoil sites. Among the herbs *Aristida adscensionsis, Chloris virgata, Hyptis suaveolens* and *pteris longifolia* were present in all the sites.

The earliest colonizing herb species were *Acanthopsermum hispidum, Aristida adscensionsis, Bidens bitemata, Chloris virgata, Cynodon dactylon, Dactyloctenium scindicum, Eragrostis tenella, Hyptis suaveolens* and *pteris longifolia*. Other herbaceous species like *Altenanthera sessilis, Atylosia scarabaeoides, Dactyloctenium aegyptium, Eulaliopsis binata, Evolvulus nummularius* and *Tridex procumbens* were present in all the sites except in 2 year old one. The late colonizing herb species were *Desmodium triflorum, Eragrostis ciiaris, Eleusine indica, Evolvulus alsinoides, Heteropogon contortus, Phyllanthus gradnerianus, Phyllanthus fratemus, Saccharum spontaneum* and *Waltheria indica*.

On the basis of IVI values of the species, six communities could be identified and these are:

1.	*Aristida - Eragrostis – Calotropis*	(2-year old site)
2.	*Tephrosia - Aristida – Calotropis*	(5-year old site)
3.	*Trema - Tephrosia – Aristida*	(8-year old site)
4.	*Trema - Cassia – Aristida*	(1 O-year old site)
5.	*Hyptis - Calotropis – Aristida*	(15-year old site)
6.	*Hyptis -Aristida – Diospyros*	(25-year old site)

Copper

In the initial stage, copper mines were underground mines except Chandmari of Hindustan Copper Ltd. During 80's, mines at Malanjkhand and Rampura-Agucha were started in open pits in Madhya Pradesh and Rajasthan. Malanjkhand mine of HCL produces 2 million tonnes copper ore per year. Here, the overburden is 4 to 7.5 m^3 per tonne of ore. Malajkhand copper mines are situated in the tribal belt of Baihar tehsil, district Balaghat of Madhya Pradesh and fall in 21 °51 '24" North latitude and 80°13'48" East longitude. The vegetation in and around Malajkhand copper mine area is mainly the result of climatic, edaphic and biotic factors coupled with altitude. Sal *(Shorea robusta)* is the dominant species in the studied area. The other associates are *Anogeissus latifolia, Bridelia retusa, Buchanania lanzan, Diospyros melanoxylon, Haldania cordifolia etc.* The overburden spoils are very coarse and mixed with rock fragments. The colour of the fresh spoil is grayish to light yellow.

In all the dump sites *Celosia argentea* has contributed much in community formation. Even in the 15-year old dump where plantation has been raised *Celosia argentea* has dominated in community formation. *Tridax pracumbens* is the other species, which has taken part in community formation in almost all the dumps except the 10-year-old dump. *Cratalaria prastrata* has also taken part in community formation to some extent and has shown its presence as a dominant species in almost all the dumps except the 5 year-old-dump where it's IVI is 28.2. Only in natural forest, where succession has proceeded to almost climax, *Cratalaria* has not taken part in community formation.

The three species namely *Celosia argentea, Tridax pracumbens,* and *Cratalaria prastrata* which have taken part in community formation in dumps as well as in plantation sites, are also found in natural forest although their IVls are not very high. *Saccharum* sp, a well known member of family Poaceae and a soil binder is absent in the natural forest. From the above findings it can be inferred that *Celosia argentea, Tridax pracumbens,* and *Cratalaria prastrata,* which are indigenous for the region are also early colonizing angiospermic flora in copper mine overburdens of the region.

Some tree species like *Butea monosperma* belonging to Papilionaceae invades in the dumps and is universally present in all the sites. The number of tree species has gradually increased in older sites. Presence of tree species is an indication of the maturity of the ecosystem. The arrival of 5 tree species in plantation site indicates that the process of succession will be quickened by plantation. A remarkable feature of the process of succession found in this study is that the dominant tree species of the region i.e. *Shorea robusta* has not been able to migrate or establish itself in any of the dumps including plantation site also. The seeds of the species being very short-lived fail to invade the problematic soils like mine spoils.

Limestone

Suitability of different forest tree species on limestone mine overburden spoil of Kuteshwar Mine situated near Katni (M.P.) was determined through pot culture experiments in TFRI nursery. 11 nitrogen fixing tree species (NFTs) and 10 non-nitrogen fixing tree species (non-NFTs) were selected to conduct pot culture experiments.

Growth parameters including stem height, collar diameter and root length and biomass attributes including leaf weight, shoot weight and root weight were measured after nine months of planting in the polybags in nursery. A suitability index was calculated by summing up the values of shoot height, collar diameter and total biomass. As per suitability index, *Acacia nilotica* followed by *Pongamia pinnata* and *Dabergia sissoo* showed the best performance among NFTs while *Jatropha curcas* followed by *Eucalyptus hybrid* and *Gmelina arborea* exhibited the best results among non-NFTs.

Nitrogen Fixing Tree Species

Acacia nilotica > *Pongamia pinnata* > *Dalbergia sissoo* > *Leucaena leucocephala* > *Peltoforum africanum* > *Delonix regia* > *Cassia siamea* > *Albizia procera* > *Acacia catechu* > *Albizia lebbek* > *Acacia auriculiformis*

Non-Nitrogen Fixing Tree Species

Jatropha curcas > *Eucalyptus hybrid* > *Gmelina arborea* > *Simaruba glauca* > *Holoptelia integrifolia* > *Azadirachta indica* > *Emblica officinalis* > *Ailanthus excelsa* > *Boswellia serrata* > *Mimusops elengi*

A number of trials both at nursery and field levels have been conducted throughout the country with a view to stress site rehabilitation. Pot trials conducted with NFT and Non-NFT species at Malanjkhand, M.P. (Williams *et al.*, 1994) have shown *E. grandis, E. camaldulensis, E. tereticornis* and *G. arborea* as the most promising species for copper mine overburdens. According to Bhowmik *et al.* (1996) in a nursery trial on iron-mine overburden with 20 species, *Leucaena leucocephala, E. hybrid, Ipomoea fistula* and *G. arborea* performed better and manifested higher suitability indices.

From another field trial on degraded soil of MP with 16 NFT and non-NFT species, Sonkar *et al.* (1994) have recommended *D. sissoo, D. latifolia, A. indica* and *E. officinalis* as the most suitable species.

RECALMATION IN EASTERN INDIA (IFP RANCHI)

Green Belt Development at Chandrapura Thermal Power Station, DVC

The areas in and around Chandrapura Thermal Power Station (CTPS), DVC are undulating with occasional hills. Most of the areas are under plantations mostly with *Cassia siamea, Dalbergia sissoo* with regeneration of *Butia monosperma, Lantana camera, Zizyphus* spp., and other common associates of dry deciduous Sal Forest. Blank areas are found within the periphery of Ash Ponds, proposed residential areas. IFP implemented a consultancy project for development of green belt with appropriate species planation and management interventions.

The soils are slightly acidic except for a few which are near neutral. The profile soil and that of the agricultural land at lowest elevation showed minimum pH. The electrical conductance values are also within normal range. Organic carbon status is very low even at lower elevation. The mechanical analysis of samples shows dominance of sand faction and soil texture is loamy sand to sandy loam, which reflects low water holding capacity. However, site to site variation in organic carbon, available nutrients and water holding capacity is very less.

Fig 19. *Green Belt Development at Chandrapura Thermal Power Station, DVC*

Distribution of magnesium was almost uniform though out the study site. Distribution of viable microorganism in soils also showed almost uniform pattern. While total bacteria present were in the order of 10^5/g dry soil, the nitrogen fixing bacteria were in the orders of 10^4/g dry soil. Total fungi and actinomyctes, however, present at the level of 10^3/g dry soil.

Soil amendments (doses per pit)

1st Year

Sl. No.	Quality Factors	Amending Materials and Doses	Time of application
1.	Liming	10g CaCO3 or equivalent per pit	Single application – 15 days before plantation mixed with soil.
2.	Insecticide	10 ml Chloropyriphos (Dursban)	Mixing l0 ml Chloropyriphos in 2 lit. water and drenching of pit soil before planting.
3.	N fertilization*	75g Urea or 170 g Amm. Sulphate	2 split doses – 1st 15 days before planting & 2nd 60 days after plantation.
4.	P fertilization	75g SSP per pit or equiv.	-do –-
5.	Zn	0.1 g $ZnSO_4 .7H_2O$	Single application – 15 days before plantation.
6.	B	0.5g Boric acid or Sod. Borate	Single application – 15 days before plantation.
7.	Mo	0.005g Amm. or Sod. molybdate	Single application – 15 days before plantation.
8.	Organic matter	1000g Rice husk (burnt or decomposed) + 1000g FYM or 2000g Rice husk + 100 mixed oil cake (Neem, Karanj, Mahua etc	Single application – 15 days before plantation and mixed with soil.

** Fertilization should be followed by immediate irrigation in absence of rainfall*

2nd Year

Sl. No.	Quality Factors	Amending Materials and Doses	Time of application
1.	N fertilization	90g Urea per pit or equiv.	2 split doses – (pre-monsoon and post-monsoon)
2.	P fertilization	75g SSP per pit or equiv.	2 split doses – (pre-monsoon and post-monsoon)
3.	K fertilization	10 g MOP per pit	2 split doses – (pre-monsoon and post-monsoon)
4.	Organic matter	Rice husk (burnt or decomposed)-1000g	Pre-monsoon application with soil work
5.	Insecticide Use	10 ml Chloropyriphos (Dursban)	Mixing l0 ml Chloropyriphos in 2 lit. water and drenching of pit surrounding the stem after fertilization and mulching.

These areas may be planted with timber producing species and emphasis should be given for maintaining biodiversity with indigenous species. The recommended species are:

Adina cordifolia, Albizzia lebbek, Albizzia procera, Azadirachta indca, Dalbergia sissoo, Emblica officinalis, Gmelina arborea, Maduca latifolia, Pterocarpus marsupium, Syzygium cuminii, Tectona grandis, Terminalia belerica, Terminalia catechu, Terminalia chebula, Terminalia tomentosa etc. with different bamboo species.

At lower lower elevation of hills 2 to 3 rows of soil binders like *cactus, Vertibera species, Agave maxicana, Lantana camara etc.* and 2-3 rows of flowering trees like *Cassia fistula, Jacaranda* sp., *Delonix regia, Lagerstroemia parviflora, L. superba, L. speciosa, Bahunia purpera etc.* may also be planted.

Soil binders and grass ands shrub species such as *Agave maxicana, Alylosia scarabaeoides, Elephantus scraber, Eulaliopsis binata, Gymnema sylvestre, Saccharum munja, Saccharum sponteneum, Vertibera species etc.* can be planted along the out slope of the embankments along with the following tree species since these sites more inclined.

For plantation along the ridges tall shelter belt trees are to be preferred and recommended. The species are - *Albizzia lebbek, Albizzia procera, Bombax ceiba, Dalbergia sisoo, Eucalyptus camaldulensis, E. teriticornis, Pterocarpus marsupium, Samania saman* and *Terminalia arjuna.*

For plantation along the Slopes medium height flowering trees and trees of denser foliage are to be preferred. The recommended species are - *Cassia fistula, Delonix regia, Erythrina indica, Jacaranda sp., Lagerstroemia parviflora, L. superba, L. speciosa, Bahunia purpera, Michelia champaca, Peltophorum ferrugineum etc.* Other species like *Acacia auriculiformis, Acacia nilotica, Alstonia scholaris, Azadirachta indca, Gmelina arborea, Maduca latifolia etc also perform well.*

Soil Moisture Conservation and Water Harvesting

Since the slope of the land extends up to about 10%, following measures in addition to soil amendments may be fruitful to conserve soil moisture and maintaining water harvesting.

- *Construction of graded or channel type terrace by cutting a shallow channel on the upper slope side and using these soils to build the embankment. The ridge back slope may be a 2:1 slope.*
- *Construction of Conservation Bench Terrace – Consisting of an earthen embankment and a very broad flat channel that resembles a level bench. Conservation bench terrace is designed to correct the deficiency of level or ridge type terrace. With reference to slope, terraces may be constructed with uniform or variable grades.*
- *Interrupted and staggered contour trench of 9.3 m x 0.3 m x 3.0 m followed by pits at an espacement as stated earlier fitted in with the alignment of contour trenches.*
- *In hilly tracts about 4.6 m long trenches having cross-sectional area of 45 cm^3 are to be dug with an interruption of 90 cm in between two contiguous trenches. Along the slope the distance is kept at about 4.6 m. The excavated earth is piled upon the lower side of the trench after hoeing the surface to a depth of 15 cm in a strip of 30 cm wide, a berm of at least 25 cm is to be left from the edge of the trench.*
- *Construction of water storage pits or Water Harvesting of size 0.75m x 1.5m x 0.75m at alternate strips at distance of 5m.*
- *Creation of check dams and gully plucking for checking severe erosion at places of higher slope gradient.*

- *Construction of Diversion Channel around the slope with a slight gradient to cause excess water to flow to the desired outlet.*

SPECIES SUITABILITY FOR RECLAMATION OF RED, LATERITE AND LATERITIC SOILS IN CHHOTANAGPUR PLATEAU

The Chhotanagpur Plateau region covering major part of the state of Jharkhand has wide variation in altitude, vegetation, rainfall and parent material. Thus, the soils developed have variable properties. The soil thickness varies from a few cm to several meters. The colour varies from red, yellow to grey and texture ranges mostly from loamy sand to clay. Similarly, the physical, physico-chemical, chemical and biological properties of these soils show wide variations.

The major problems associated with the red, laterite and lateritic soils of Jharkhand that support the forests of the state are acidity, low water retention capacity and high permeability, low levels of organic matter, available nitrogen and phosphorus and unavailability and toxicity of some of the micronutrients. Therefore studies were done aiming at-

- *assessing the nature and degree of degradation and other tree growth limiting factors,*
- *evaluating suitable multipurpose tree species for these degraded soils based on their growth performances and*
- *developing suitable packages for the reclamation of these degraded sites with suitable soil amendments keeping in view the maintenance of soil moisture level on sustainable basis.*

Field survey has been conducted to collect features on field parameters of Lalgutwa area representing Chhotanagpur Plateau in terms of physiography, relief, soil, vegetation etc. Soil samples collected from multiple sites have been analyzed. The physical, physic-chemical and nutritional parameters including the surface soil characters, geology, soil forming processes have also been analyzed and the tree growth limiting factors and other soil constraints have been identified.

Nursery and field trials have been conducted for suitability study as per standard procedures. The following 69 species have been evaluated for their suitability through growth and biomass production:

Acacia auriculiformis, A. catechu, Acacia mangium, Acacia nilotica,Adenanthera pavonina, Aigle marmelos, Ailanthus excelsa, Albizia amara, A. Chinensis, A. Lebbek, Albizia lucida, A. odoretisima, Albizia procera, A. richardiana, Alstonia scholaris,Anacardium occidentale, Annona squamosa, Anthocephalus cadamba, Artocarpus integrifolia, Ausculus assaica, Azadirachta indica, Bauhinia variegata, Bombaux ceiba, Butea monosperma, Callistemon lanceolatus, Cassia fistula, Cassia nodusa, Cassia siamea, Ceiba pentendra (Green), Ceiba pentendra (White), Dalbergia latifolia, Dalbergia sissoo, Delonix regia, Dillenia indica, Diospyros melanoxylon, Eucalyptus brassiana Eucalyptus camaldulensis, Ficus glomerata, Gmelina arborea, Holoptelia integrifolia, Jackaranda mimosifolia, Kigellia pinnata, Leuceanea leucocephala, Madhuca indica, Mnelia azadiracht, Mesua ferreay, Mimosops elengi, Oroxylum indicum, Peltopherum ferrugineum, Pithecellobium dulce, Polyalthia longifolia, Pongamia pinnata, Pterocarpus marsupium, Pterospermum superifolium, Samania saman, Saraca asoka, Schleichera oleosa, Shorea robusta, Simaruba glauca, Spathodea campanulata, Stercullia foetida,Swietenia mehagoni, Syzygium cuminii, Tamarindus indica, Tectona grandis, Terminalia arjuna, Terminalia belerica, T. chebula, T. tomentosa, Zizyphus zujuba.

Among the 69 species tested for screening suitable species for degraded soils of Lalgutwa, more than 25 species were leguminous and produce a sizeable proportion of root nodules. After completion of the pot trial by 180 days and field trial by 3 years, the suitability indices of the species have been worked out and accordingly suitability rankings have been provided. The suitable species have been recommended for large scale plantation in the region.

The following 34 species may be treated as more suitable than the others for Chhotanagpur Plateau soil. These are *A. richardiana, C. pentandra* (var. Green and White), *L. leucocephala, S. saman, M. azadiracht, A. mangium, F. glomerata, A. nilotica, P. dulche, E. camaldulensis, A. auriculiformis, T. arjuna, A. amara, D. sissoo, D. regia, Bauhinia veriegata, G. arborea, Tamarindus indica, P. pinnata, E. brassiana, H. integrifolia, P. superifolium, S. glauca, D. latifolia, A. lebbek, K. pinnata, A. procera, A. cadamba, Z. zujuba, A. integrifolia, B. ceiba, C. siamea* and *T. tomentosa.*

However, on the basis of only height and diameter growth, the promising species are: *A. richardiana, C. pentandra (var. Green), M. azadiracht, C. pentandra (var. White), L. leucocephala, E. camaldulensis, H. integrifolia, F. glomerata, Bauhinia veriegata, A. scholaris, D. sissoo, T. arjuna, S. saman, A. amara, A. nilotica, E. brassiana, A. auriculiformis, G. arborea, K. pinnata, D. regia, A. mangium, P. pinnata, D. latifolia, J. mimosifolia, T. tomentosa, Z. zujuba, P. dulche, S. foetida, A. cadamba, A. lebbek, B. ceiba,* and *S. glauca.*

RECLAMATION OF DEGRADED SOILS OF CHHOTANAGPUR PLATEAU REGION WITH ORGANIC AND LIMING MATERIALS

In order to develop the reclamation strategy for degraded soil of Chhotanagpur, Two sets of field trials have been conducted at Lalgutwa having identical degraded soils as noted in most part of the plateau region. In one trial, degraded soil has been amended with five different types of bulky organic matter including agricultural and forest wastes with and without inorganic fertilizers and micro-nutrients at different doses taking *Gmelina arborea* as the test species. At regular intervals and after completion of the trial, growth parameters of the test species, changes in soil attributes and foliar nutrient levels have been assessed so as to measure the effect of the amending materials. In the other trial, in place of organic amendments, liming materials of different sources have been utilized and two new species, *Madhuca indica* and *Pongamia pinnata* have been treated as the test species.

The superiority of the bulky organic materials in enhancing the height and diameter of *G. arborea* has been in the decreasing order of Vermicompost (VC) > Rice husk (RH) > Forest litter (FL) > Saw dust (SD) > Rice straw (RS) > Control during the first year. The decreasing orders of the influencing effect after second year have been VC > RH > SD > RS > FL > Control in height increment and RH > SD > RS > FL > VC > Control in collar diameter. After the third year, the corresponding orders have been RH > SD > FL > RS > VC > Control in height growth and SD > RH > FL > VC > RS > Control in collar diameter.

It is clear that the materials having comparatively more available plant nutrients or lower C:N ratio like VC performed better after application as direct influence during the initial phases plant growth. Materials with wide C:N ratio impart better soil physical condition and influence the plant growth more as residual effect. The bulky materials like RH, SD and FL have special role in correcting the soil health physically performed better residually. These brought about higher growth increment of *G. arborea* during the third year growth. Inorganic fertilizers and micronutrient mixture have accentuated the direct and residual influence of the organic amedments and in alomost all cases the higher doses are found to be more effective than the lower doses.

All the soil ameliorating agents have shown positive response in enhancing the growth of the test species i.e., *G. arborea, P. Pinnata* and *M. Indica.* It is noted that all the soil parameters studied have been substantially improved due to the amendments. The organic amendments, when considered separately, have afftected both the physical environment as well as the nutrient levels positively. While the inorganic amendments have little or no role in improving the physical health of the soil under *G. arborea*.

It is clear that the materials having comparatively more available plant nutrients or lower C:N ratio like Vermicompost performed better after application as direct influence during the initial phases plant growth.

Fig 20. *Pot trial for species suitability at lalgutwa*

Fig 21. *Field trials of species suitability in Chhotanagpur Plateaue*

In Sambalpur, Odissa, suitability and performance of different tree species in skeletal soil have been undertaken (Singh *et al.* 1992) and based on survival and growth after 18 months, *A. auriculiformis, Albizzia procera, G. arborea, P. ferrugineum, D. sissoo, Cassia siamea* and *E. hybrid* performed well. However, *Pithecellobium dulce* failed completely.

According to Gupta *et al.* (1994), however, *P. dulce* has been found to be the most suitable promising species for coal mine overburdens followed by *Simaruba glauca, Cassia siamea, D. sissoo* and *P. pinnata* as observed from field trials in Odisha.

It may be pointed out that the list of suitable species, as evaluated through pot and field trials and their growth and biomass production, have their mention as promising species for other degraded and stress sites (Prasad, 1988, 1992; Awasthi and Pal, 1993). Nath *et al.* (1990) studied the suitability of species for social forestry programme and observed that *Acacia auriculiformis, Albizzia lebbek, Cassia siamea, D. sissoo, Eucalyptus spp., G. arborea,* and *Peltopherum ferrugineam* have expressed moderate to excellent growth under degraded lateritic soil of South West Bengal.

EFFECT OF MANAGEMENT PRACTICES OF COAL MINE SOILS

Coal mine soil had 83% coarse fragments. It is un-weathered, acidic and sandy texture. Added organic manures changed physico-chemical properties of raw coal mine significantly. Notably, organic manures and sand are reduced both bulk density and pH to optimum level and enhanced organic carbon and nitrogen level significantly in raw coal mine soils. As coal mine soils are un-weathered materials, it could not supply any nutrients for plants. As weathering starts, nutrient supplying capacity of coal mine soils begins.

As it is an inert media, the plants depending up on external nutrient source for growth and development up to partial weathering. Raw coal mine soil is successfully amended and reclaimed successfully with organic manures viz. vermicompost, poultry manure, FYM, bio-char, saw dust and municipal wastes along with sand. The amended coal mine soil used as excellent absorbent media for soil carbon sequestration through enhanced biomass production.

Management practices (MPs) help in converting un-weathered coal mine soils into productive land. As coal mine soils are highly degraded, it has great potential for carbon sequestration potential. Organic matter can be restored to about 60 to 70% of natural levels with best farming practices. The coarse fragment content of coal mine soil was greater than 83%. Since mine soils are sandy in texture, it cannot hold as much water or nutrients. Coal mine soil is almost un-weathered parent materials and acidic in nature. Organic manures viz., vermicompost, FYM, poultry manure, bio-solids, bio-char and saw dust would help to make coal mine soil as productive by bringing its physical and chemical properties to desired level.

Besides these, sand plays a vital role in improving porosity by reducing bulk density. Further, both silt and clay per cent are increased about 5%. The bulk density is reduced to the optimum. The WHC of vermicompost treated mine soil is higher than that of vermin-leachate treated mine soil and control. Vermicompost cause reduction in pH and reverse trend observed in vermileachate applied coal mine soils. The EC of 3-month old vermin-composted mined soils is decreased nearly ten-fold of that of the EC value of freshly coal mine soils.

The organic carbon (OC) content is increased significantly. Both organic carbon and organic matter content was reduced to 50% from that of in beginning of the experiment. The per cent of available nitrogen and available phosphorus had shown decreasing trend with quantity of organic manures addition in 3-month old mined soils. Available P is lower than that of available N and K due to reduction in soil microbes and presence higher proportion of un-weathered parental materials. The exchangeable $K+$ content was found to be higher in all in 3-month old mined soils. The Mg^2+ content was found to increased many fold at end of 3rd month from the level of it at beginning. It was observed that the CEC had increased significantly during study period in all treated mine soils with a few exceptions.

Seed germination response of *Swetenia macrophylla* and *Prosopis juliflora* in vermicompost treated mine soil is on par with that of *Acacia nilotica* and *Dalbergia sissoo*. *Acacia nilotica* and *Dalbergia sissoo* are considered most suitable species for revegetation of vermicompost treated coal mine sites as these species are N2 fixers. It is concluded that *A.nilotica* and *D.sissoo* are suitable tree species for reclamation of coal mine soils as these species are N2 fixers, drought hardy and pioneer in early succession.

The porosity of all species plots was significantly higher than that of control. The porosity, water holding capacity and volume were higher in *G. arborea* plot. Interestingly, the bulk density of all top-soil incorporated plots had higher value than that of control. The highest bulk density was found in top-soil added *D.sissoo* plot where as top-soil added *G.arborea* plot had lowest bulk density. On other hand, the porosity, water holding capacity and volume were lower in all top-soil added plots.

Both the species and organic manures had significant effect on improvement of coal mine soils. The bulk density of organic manure- added coal mine plots follows the order viz. vermicompost plot > FYM plots > Poultry manure plots. Both particle density and porosity of manured plots was FYM plots > Vermicompost > Poultry manures.

The results of trial with bio-solids and organic manures show that organic manures and bio-solids were caused significant changes in chemical properties of coal – mine soil. Both survival % and rate of height growth varied significantly with amount of manures added to coal mine soils. Among 3 test species, mahua was performed very poorly and jamun is outstanding performer in the amended coal mine soil with respect to survival %, plant height and biomass at lower doses of organic manures. The performance of sal in manured coal mine soil was poor like mahua.

Sal is a poor performer in amended coal mine soils. No plant was found survived in organic treatments except control. Further, the biomass production was increased significantly with increasing soil fertility due to organic manuring and bio-solids addition. It is concluded that the jamun performed well in amended coal mine soil, it may be used for reforestation and rehabilitation of coal- mine soils. Further, sal and mahua are poor performed tree species. These would not fit for reforestation of coal mine soils.

The green manuring trial on biomass production revealed that biomass production was increased significantly with increasing soil fertility due to green manuring. From the results of the study, it is concluded that organic manures, bio-solids, saw dust and biochar are played a vital role in modification of physico- chemical properties of coal mine soil for plant growth.

Overall findings reveal that among 8- tree species tested, *Acacia nilotica, Swietenia macrophylla, D.latifolia, G.arborea* and jamun *(Syzygium cuminii)* are potential species for reclamation and re-vegetation of coal mine soils. Among these success species, jamun is most preferred one. On other hand, *Prosopis juliflora*, *Shorea robusta* (sal) and *Mahua latifolia* (mahua) could not perform well in the coal mines. Besides, repeated green manuring is proved as a cost – effective management practice for reclamation and restoration of coal mine soils as its improves soil fertility and enhanced biomass production.

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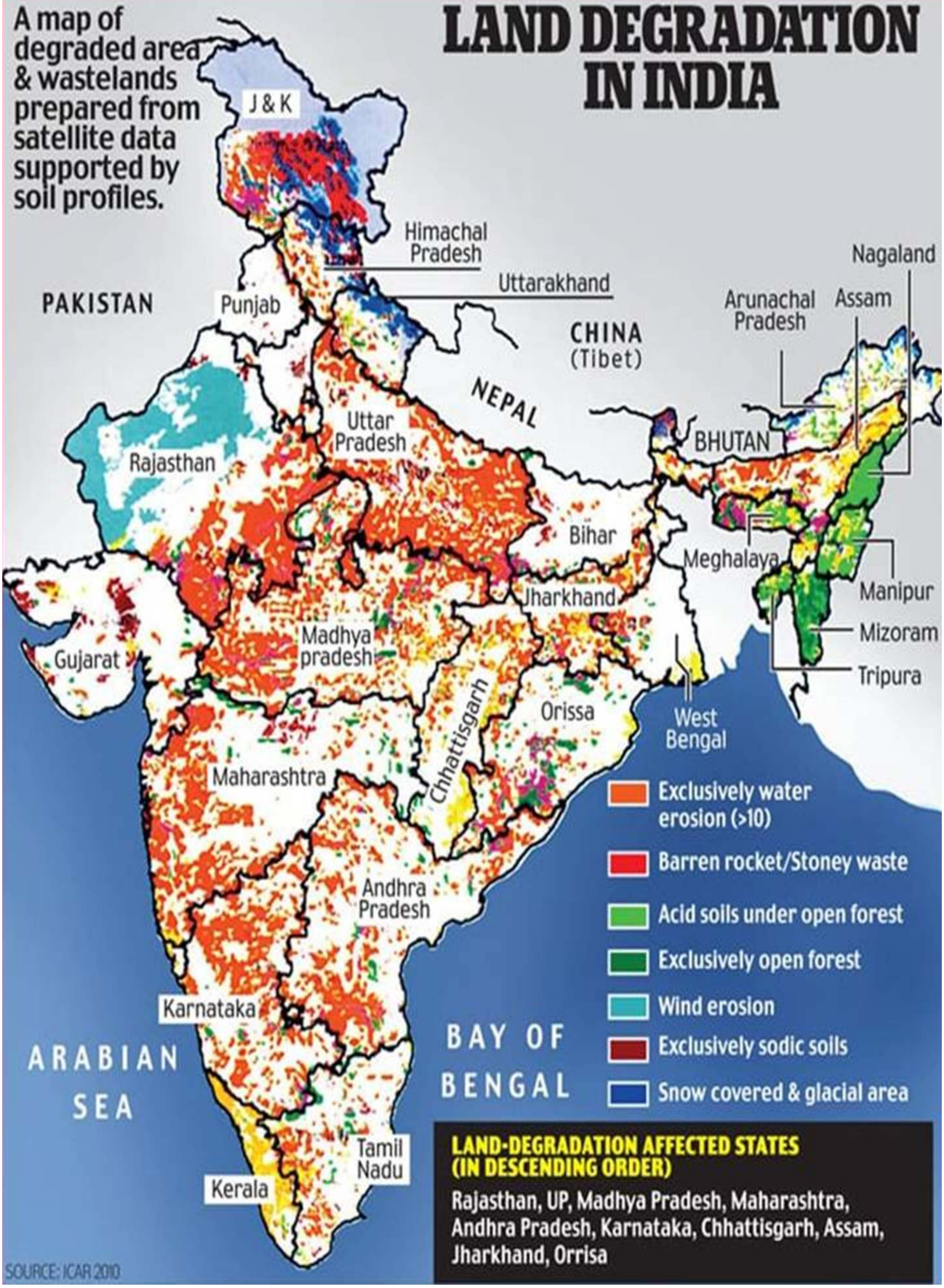


LAND DEGRADATION IN INDIA
A map of degraded area & wastelands prepared from satellite data supported by soil profiles.
J & K
Himachal Pradesh
Uttarakhand
Punjab
PAKISTAN
CHINA (Tibet)
NEPAL
Uttar Pradesh
Rajasthan
BHUTAN
Arunachal Pradesh
Assam
Nagaland
Bihar
Meghalaya
Manipur
Jharkhand
Mizoram
Tripura
Gujarat
Madhya pradesh
Chhattisgarh
Orissa
West Bengal
Maharashtra
Andhra Pradesh
Karnataka
Tamil Nadu
Kerala
ARABIAN SEA
BAY OF BENGAL
Exclusively water erosion (>10)
Barren rocket/Stoney waste
Acid soils under open forest
Exclusively open forest
Wind erosion
Exclusively sodic soils
Snow covered & glacial area
LAND-DEGRADATION AFFECTED STATES (IN DESCENDING ORDER)
Rajasthan, UP, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Chhattisgarh, Assam, Jharkhand, Orrisa
SOURCE: ICAR 2010

Open cast mining scenario

Degradation through open cast mining

A view of underground mining

Backfilling and spreading of top soil in backfilled areas

Establishment of plantation on OB dump

Successful reclamation of mined out areas

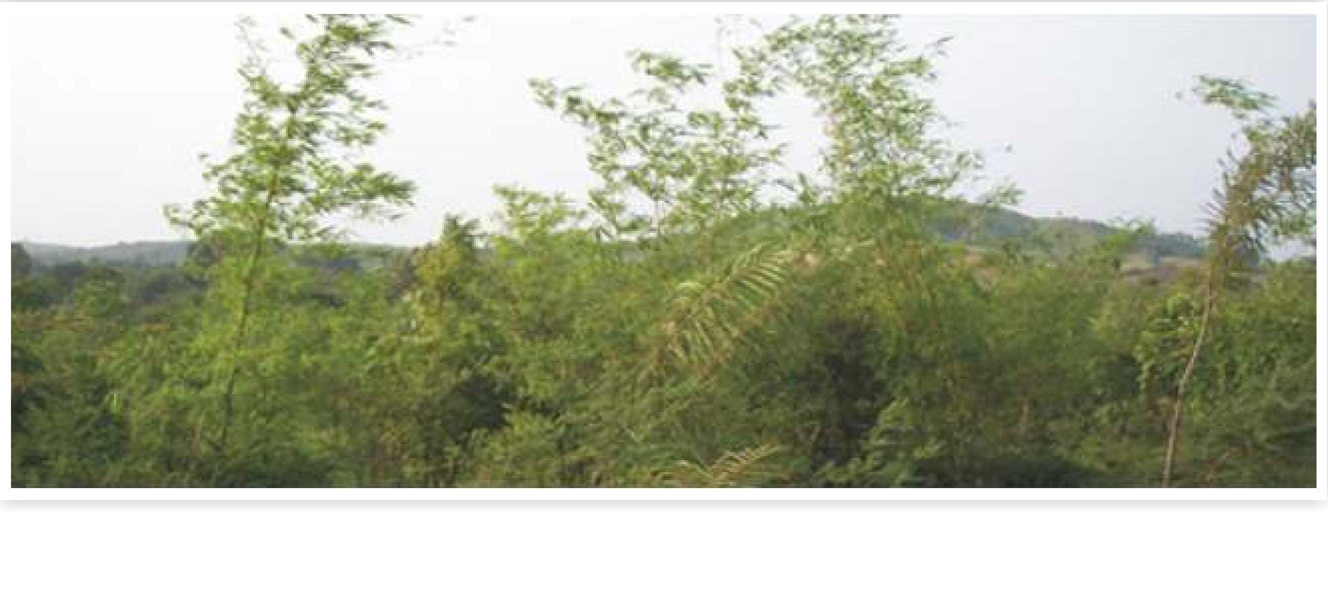
Bauxite mined out areas

I Year

II Year

III Year

IV Year

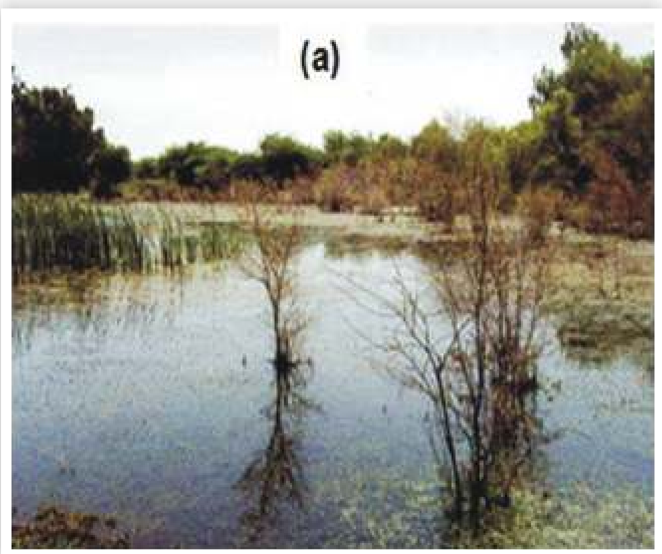


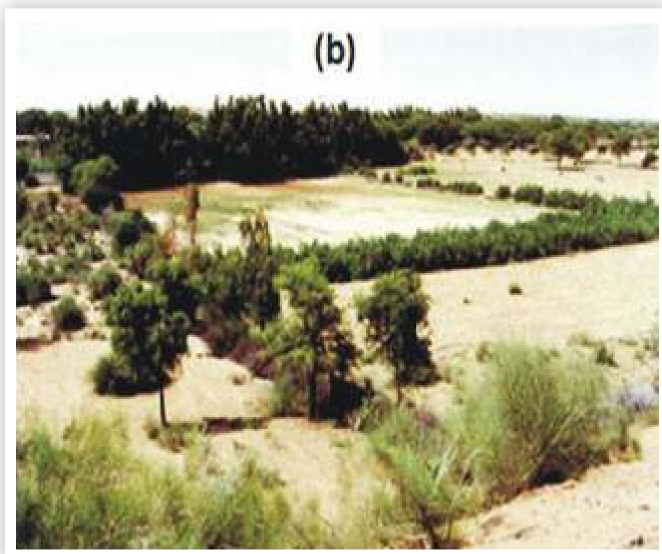
Green Belt Development at Chandrapura Thermal Power Station, DVC

Biodiversity park developed on a Coal Mine site

Pot trial for species suitability at latigation

Field trials of species suitability in Chhotanagpur plateue





(a) In undated area cost by leakage alongside IGNP main irrigation canal

(b) Trees in background are the biodrainage system that dried up the inundated areas along the main canal

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